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BRIAN MAY

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- Over 1 trillion stars
- 9 billion years old

JUPITER
KING OF THE PLANETS

How the gas giant controls the outer Solar System

SPACE JUNK CRISIS

Could orbital debris halt exploration?

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ICARUS PATHFINDER
HOW TO SEE THE STARS
GENE KRANZ

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Blast off into a universe of knowledge

Amazingly, you can see the next nearest galaxy to the Milky Way with the naked eye despite the fact that it's 2.5 million light years away from Earth. Our galactic neighbour, called Andromeda, is very similar to our own galaxy being of the spiral variety and centred around a huge black hole believed to be up to 230 million times more massive than our Sun. It's truly a fascinating and mind-blowing subject and one that appealed to us so much that we made it the subject of our cover feature this month. Turn to page 34 and explore this amazing place for yourself.

The National Aeronautics and Space Administration is undoubtedly the greatest space agency in the world and this issue **All About Space** takes a look at the many achievements that earned NASA this accolade. From the first American satellite launched in 1958 to the discoveries still being made by the likes of Kepler and Hubble, the milestones reached in NASA's lifetime surpass the scientific and technical to become cultural events that shape the very history of humanity. Take some time to read the article and let us know if you agree or disagree with our choices.

Other highlights waiting inside include an interview with rock god and doctor of astronomy Brian May and a look at the space junk crisis that threatens the future of space exploration. Enjoy the issue.

Dave Harfield
Editor in Chief

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Crew roster

Jonathan O'Callaghan

■ Jonathan jumped at the chance to write about NASA's greatest achievements this issue as it's a subject very close to his heart

Shanna Freeman

■ Shanna tackled a big topic this issue in the shape of our 'All About …' feature on Jupiter, the biggest planet in the Solar System

Tom Harris

■ Tom returns to **All About Space** to explore the subject of space junk and whether it could hamper future exploration

Gemma Lavender

■ A new addition to our roster, Gemma has worked as a science journalist for three years and contributed the excellent Andromeda article

Elizabeth Howell

■ Space geek and travel addict Elizabeth was the perfect writer to contribute an article on touring alien worlds around Gliese 581

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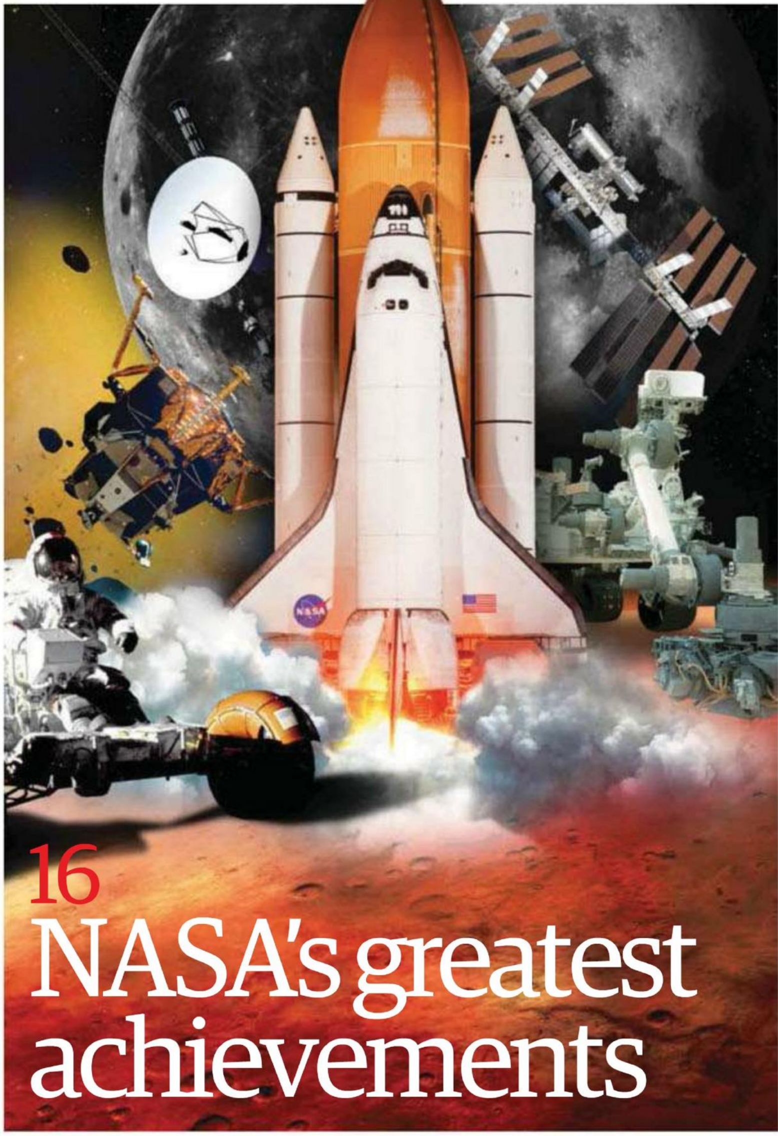

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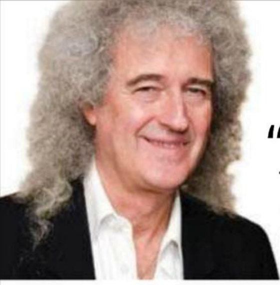

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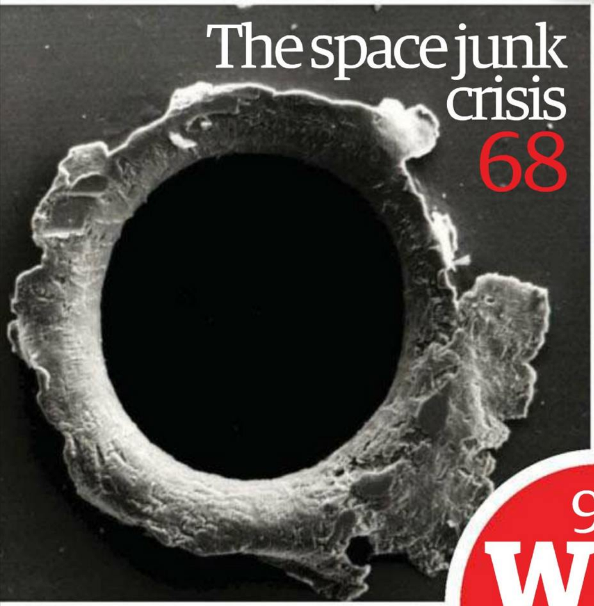

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Space Answers

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Top space experts answer your cosmic queries

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Heroes of Space

All About Space looks back on the life and career of Gene Kranz

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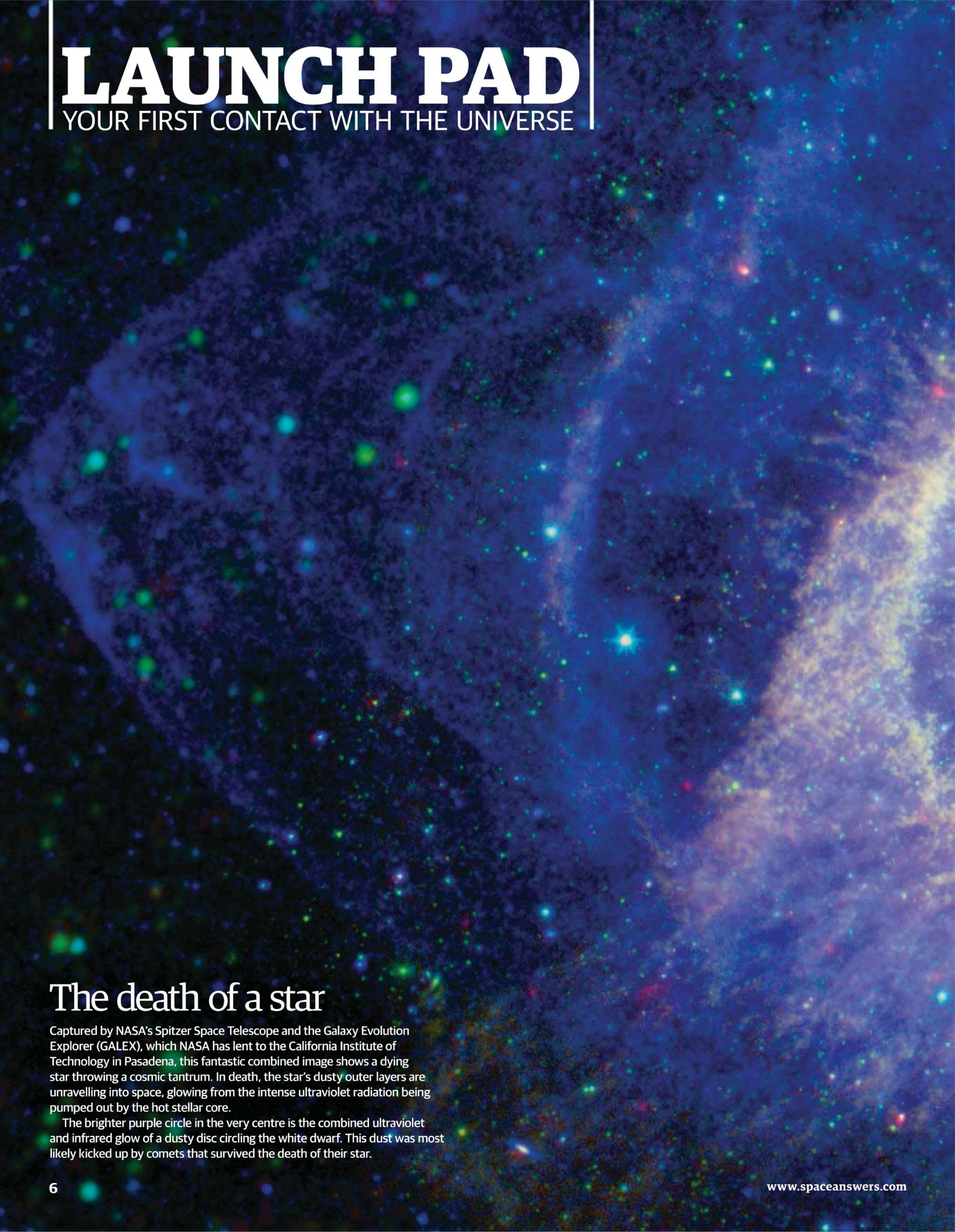
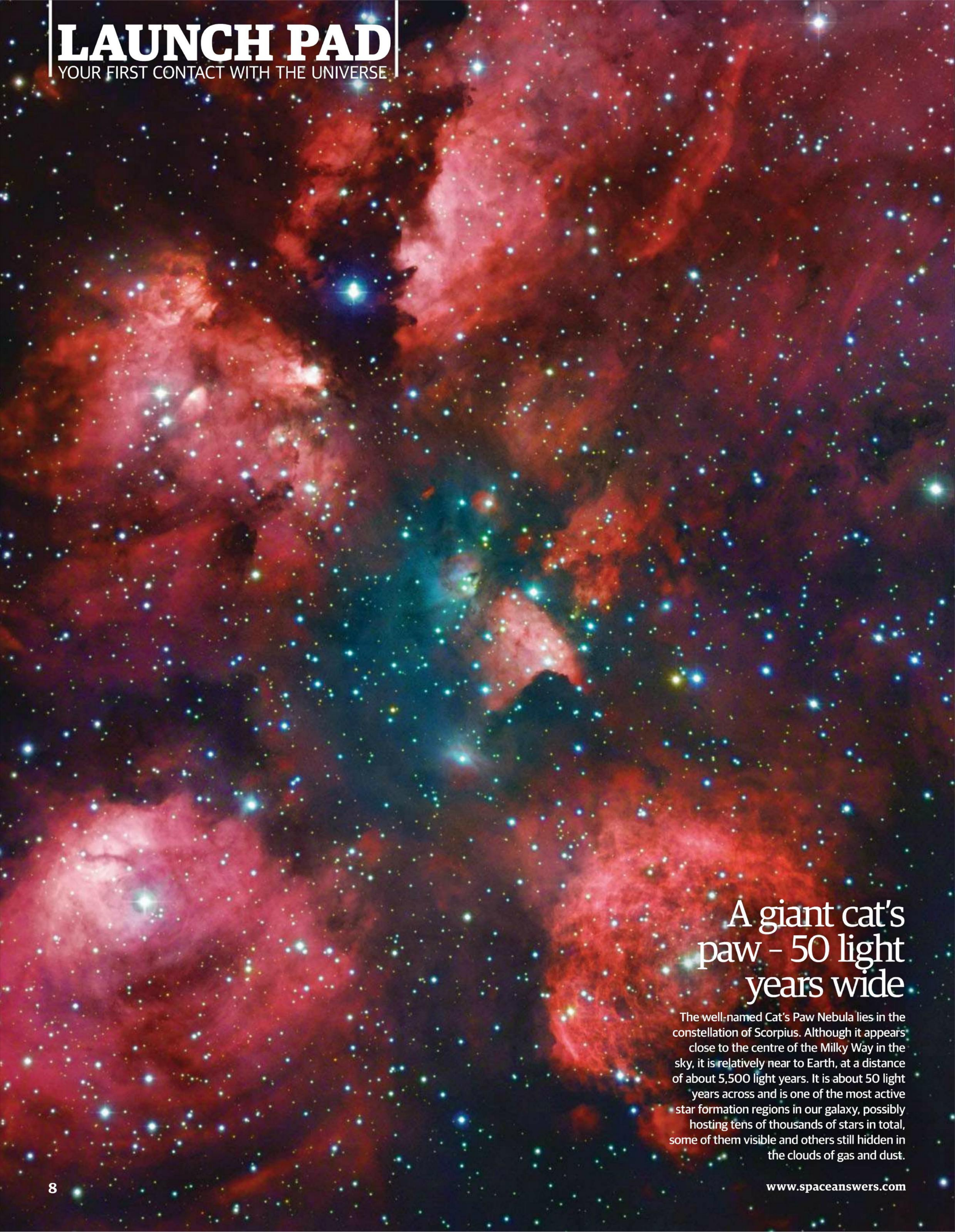


The death of a star

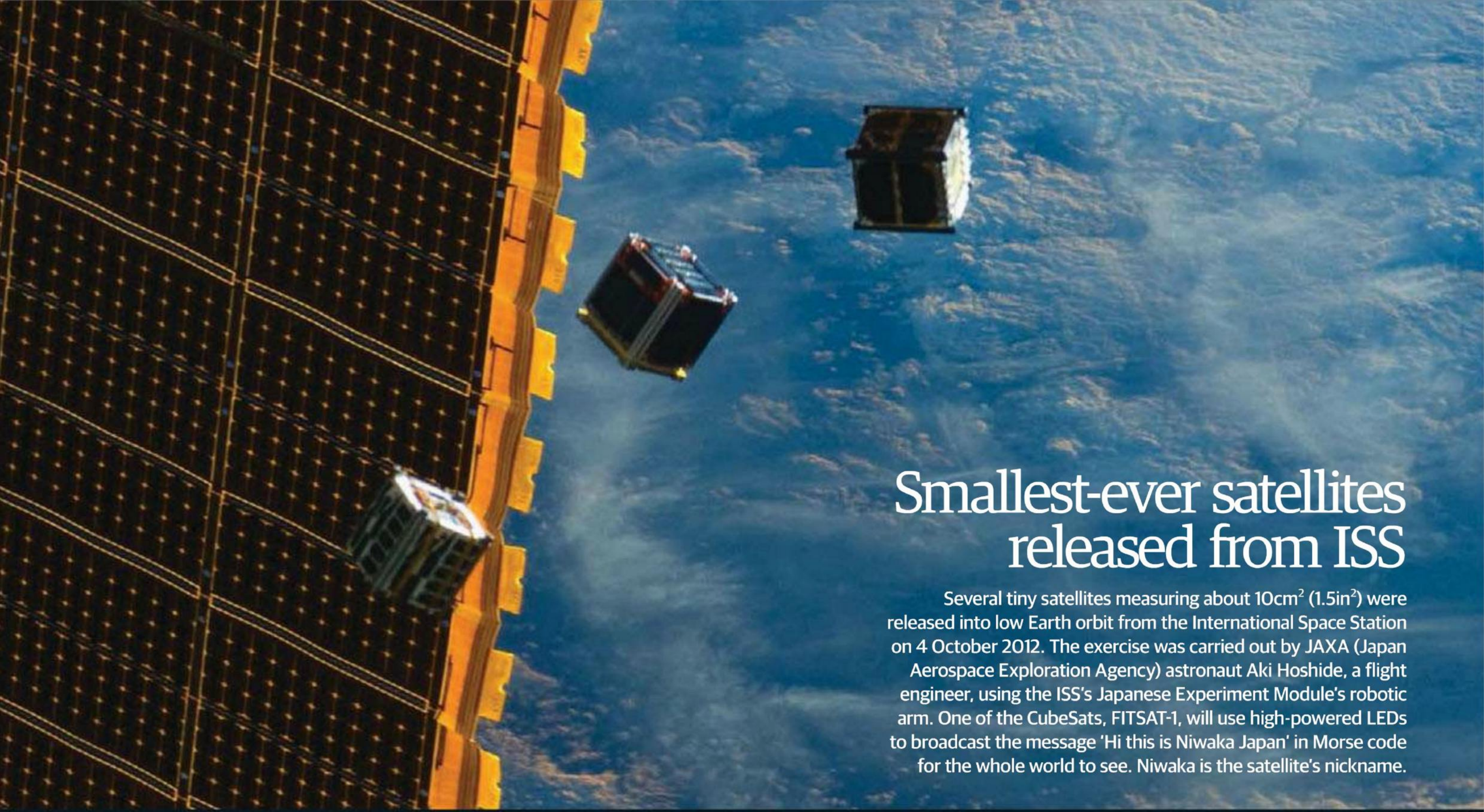
Captured by NASA's Spitzer Space Telescope and the Galaxy Evolution Explorer (GALEX), which NASA has lent to the California Institute of Technology in Pasadena, this fantastic combined image shows a dying star throwing a cosmic tantrum. In death, the star's dusty outer layers are unravelling into space, glowing from the intense ultraviolet radiation being pumped out by the hot stellar core.

The brighter purple circle in the very centre is the combined ultraviolet and infrared glow of a dusty disc circling the white dwarf. This dust was most likely kicked up by comets that survived the death of their star.



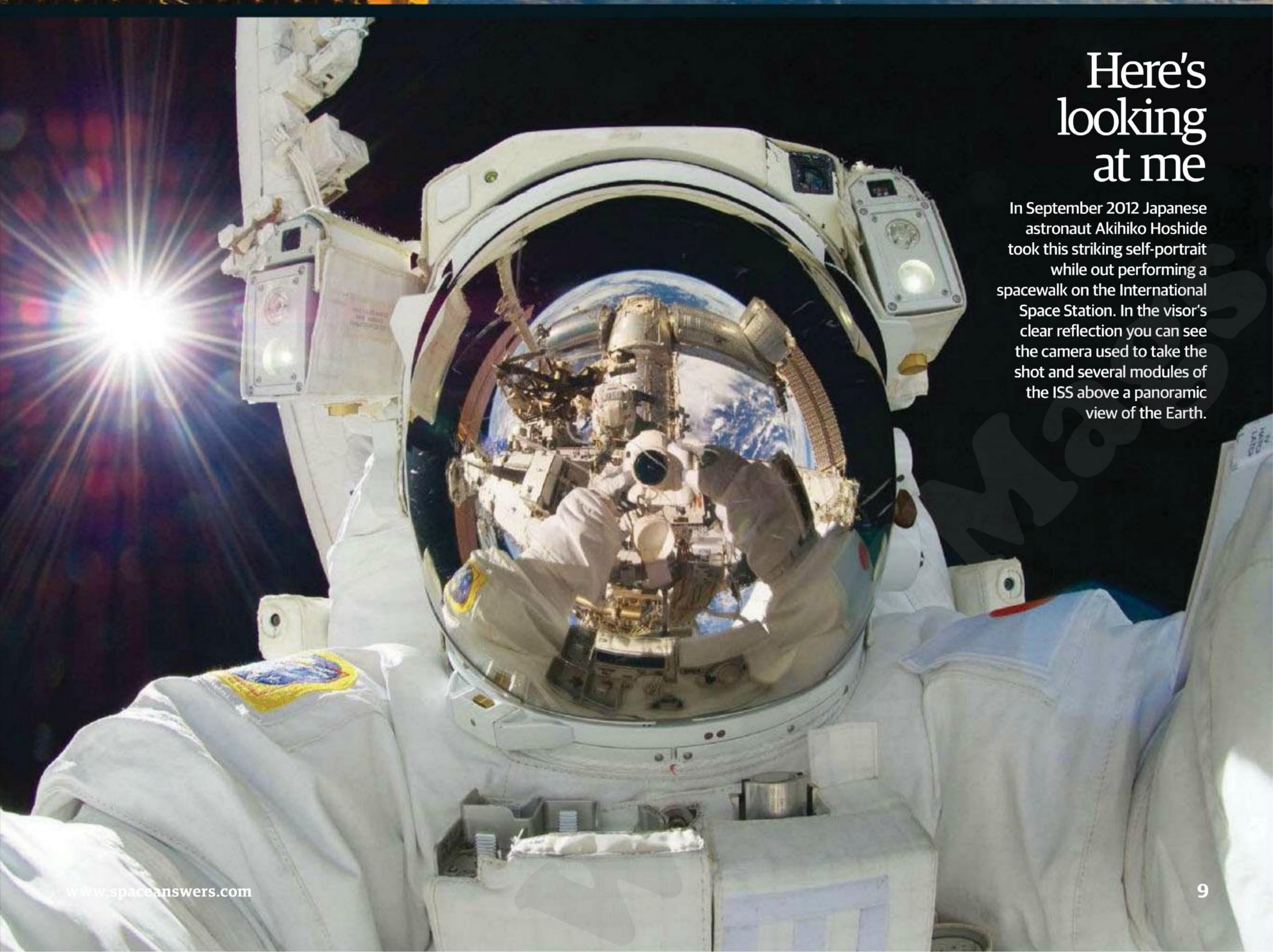
A giant cat's paw – 50 light years wide

The well-named Cat's Paw Nebula lies in the constellation of Scorpius. Although it appears close to the centre of the Milky Way in the sky, it is relatively near to Earth, at a distance of about 5,500 light years. It is about 50 light years across and is one of the most active star formation regions in our galaxy, possibly hosting tens of thousands of stars in total, some of them visible and others still hidden in the clouds of gas and dust.



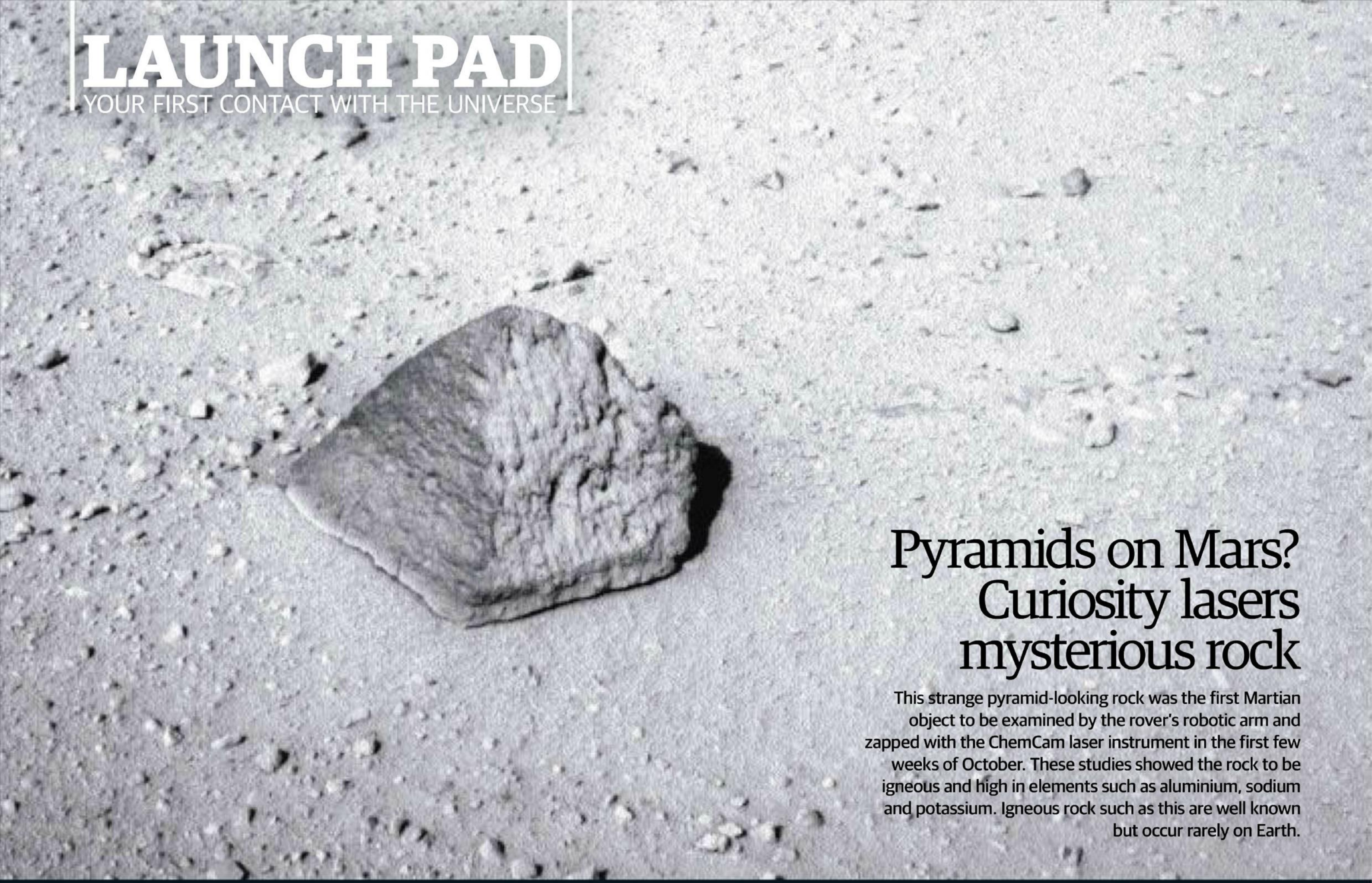
Smallest-ever satellites released from ISS

Several tiny satellites measuring about 10cm^2 (1.5in^2) were released into low Earth orbit from the International Space Station on 4 October 2012. The exercise was carried out by JAXA (Japan Aerospace Exploration Agency) astronaut Aki Hoshide, a flight engineer, using the ISS's Japanese Experiment Module's robotic arm. One of the CubeSats, FITSAT-1, will use high-powered LEDs to broadcast the message 'Hi this is Niwaka Japan' in Morse code for the whole world to see. Niwaka is the satellite's nickname.



Here's looking at me

In September 2012 Japanese astronaut Akihiko Hoshide took this striking self-portrait while out performing a spacewalk on the International Space Station. In the visor's clear reflection you can see the camera used to take the shot and several modules of the ISS above a panoramic view of the Earth.



Pyramids on Mars? Curiosity lasers mysterious rock

This strange pyramid-looking rock was the first Martian object to be examined by the rover's robotic arm and zapped with the ChemCam laser instrument in the first few weeks of October. These studies showed the rock to be igneous and high in elements such as aluminium, sodium and potassium. Igneous rock such as this are well known but occur rarely on Earth.

Looking down from the heavens

Astronaut Tracy Caldwell Dyson gazes down at Earth from a window on the International Space Station. The largest window in space forms part of the Cupola module, which was built by the European Space Agency for experiments, dockings and observations of Earth.

Dragon roars into space on first supply run to ISS

SpaceX's unmanned Falcon 9 rocket roared into the Florida night sky with the Dragon capsule on 8 October 2012. It became the first private spacecraft to supply the International Space Station. It carried around 450kg (1,000lb) of science experiments and other vital supplies to the astronauts currently on board. The sucessful mission has cleared the way for the next 11 cargo runs, restoring a US supply line to the ISS that was cut off with the retirement of the Space Shuttle fleet.

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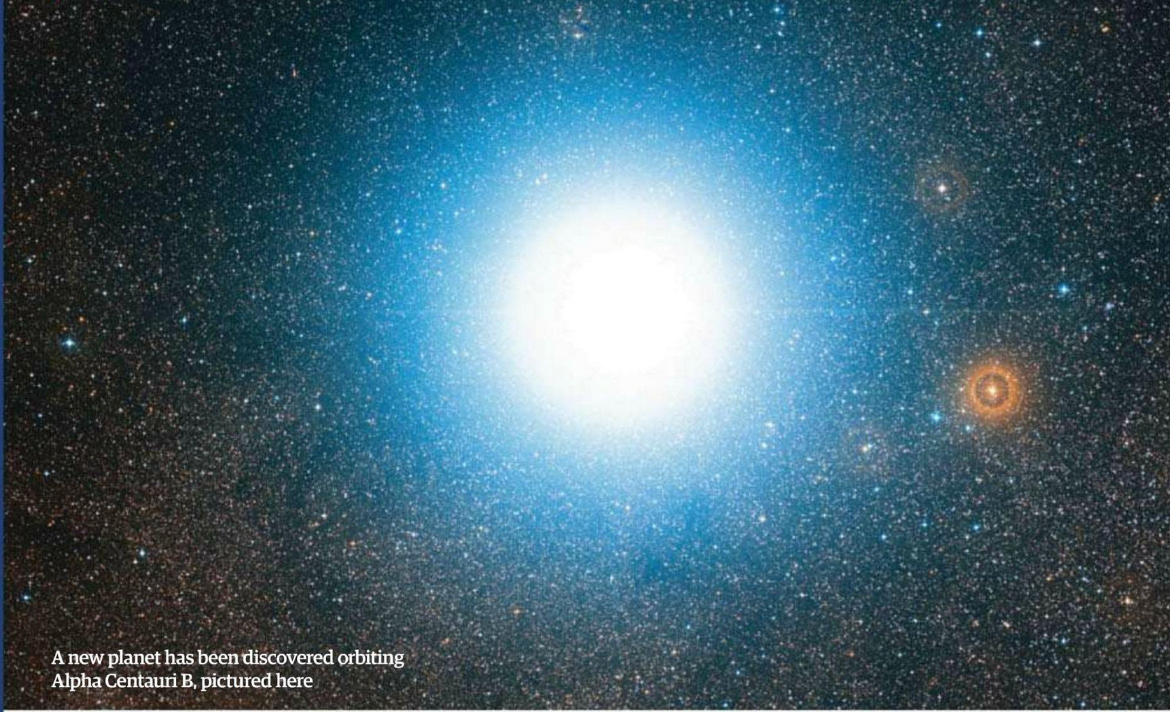

A new planet has been discovered orbiting Alpha Centauri B, pictured here

Chris Lintott, presenter on the BBC's *The Sky At Night*

"It feels possible to visit a different solar system"

BBC Sky At Night presenter Chris Lintott reveals that the discovery of a new planet just 4.3 light years away may accelerate interstellar travel

A planet has been found in our cosmic backyard just over four light years away that could one day be the focus of an interstellar exploration mission.

"Four light years is still a long way," said Chris Lintott, presenter on the BBC's *The Sky At Night*, to **All About Space**. "If you took the fastest spacecraft ever built and you sent it towards Alpha Centauri it would [still] take 75,000 years. But you start speculating about all sorts of different technologies for getting up to speed, you start thinking about how you might accelerate the spacecraft, and you could think about getting there in centuries. It begins to feel possible that we could go and visit a different solar system. That's really cool."

The planet, dubbed Alpha Centauri Bb, is located in the Alpha Centauri star system 4.3 light years away, the nearest star system to our own. It was discovered by European astronomers using the La Silla Observatory in Chile, run by the European Southern Observatory. As well as being our nearest exoplanet it is also the lightest planet ever found around a Sun-like star, with a mass no less than 1.13 times that of Earth.

The planet orbits just 6 million kilometres (3.7 million miles) from its host star, much closer than the orbit of Mercury to our Sun, and therefore it is likely rocky, molten and inhospitable to life as we know it. Despite this, however, its proximity may make it a realistic target for an interstellar probe. The technologies we'd use to get there are unknown, but a fusion spacecraft (see the Icarus Pathfinder on page 60) could do the job.

The next nearest confirmed exoplanet to Earth is Gliese 876 d, 15 light years away, making the discovery of a planet as close as Alpha Centauri Bb all the more important. It's a find that "made my jaw drop," said Lintott, and one that will likely spur the discovery of other Earth-size worlds just a few light years away. ●

A team using the La Silla Observatory in Chile announced the discovery in mid-October

The planet orbits a triple star system consisting of Alpha Centauri A and B and Proxima Centauri

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Curiosity gets scoop on Mars

NASA rover begins analysing Martian soil samples

One of Curiosity's most-impressive instruments is CheMin, which allows it to take pinches of dust from Mars and analyse them in an on-board lab. Following testing of its various systems, Curiosity has now started to analyse various samples from the Martian surface, which will allow it to analyse the composition of Mars's surface like never before.

"We are crossing a significant threshold for this mission by using CheMin on its first sample," said Curiosity's project scientist John Grotzinger. "This instrument gives us a more definitive mineral-identifying method than ever before used on Mars."

The first sample was taken on Curiosity's 69th Martian day of operations on 17 October, when a sample comparable in size to a baby aspirin was delivered into CheMin for analysis. Continued use of this remarkable instrument, in tandem with nine other instruments, will allow researchers to move closer to their goal of determining whether Mars has ever had conditions suitable for the presence of microbial life. ■

Recyclable rockets by 2020, says Russian Space Agency

The rocket that returns to the launch site after use will be 'greenest ever'

Your standard rocket booster could be a thing of the past by 2020 as the Russian Federal Space Agency have put the wheels in motion for one of the most ingenious ideas for spaceflight yet – a rocket that not only returns to its launch site after a jaunt in space, but can also be used more than once making it possibly the 'greenest' rocket ever, lowering the cost of space exploration.

The Re-entry Rocket Module (RRM) and the Reusable Integrated Launch Vehicle (RILV) will be combined, with the RRM designed to operate for a good 100 launches while its main propulsion unit, the four liquid-propellant rocket engines, will burn liquid oxygen, methane and kerosene with the goal of reigniting for 25 uses before heading home with the aid of a wing combined with air-breathing jet engines. "The RRM nose shape is optimised for the aerodynamic needs of re-entry flight and to accommodate the booster's jet engines, fuel tank, pneumatic and hydraulic mechanisms, and avionics," explains Khrunichev State Research and Production Space Center's deputy general director Anatoly Kuzin based in Moscow.

"We will finish the [RRM booster's] preliminary design by September 2013, and our next step will be the development of the demonstrator system," Kuzin says of the project which currently has two designs for the rocket in the works.

Once built and set into motion, the next-generation rocket will reach speeds of up to seven times the speeds of sound and release the RILV, which will put at least 25,000kg (55,000lb) into a low Earth orbit. ■

The new Russian rockets (inset) will do away with expendable components on modern rockets

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Russians double length of ISS visits

Current crews to the ISS stay on the station for just six months before being replaced. However, Russia says that by March 2015 crews could stay there for a year, which will help prepare for future deep space manned endeavours.

LHC will not destroy Earth, rules court

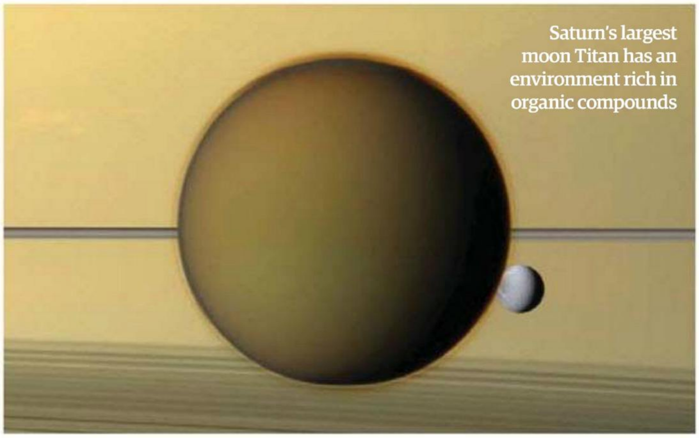
A German citizen has lost their case to shut down the Large Hadron Collider at CERN after a court in Münster, Germany, ruled that the atom smasher will not create an Earth-consuming black hole.

Planet with four suns discovered

A gas giant around 5,000 light years away from Earth has been found in a bizarre double-binary system with four stars. Over six times the size of our home planet, the gas giant is in a stable orbit possibly due to the presence of other planets.

Pluto's moons threaten NASA spacecraft

The New Horizons spacecraft, due to arrive at Pluto in 2015, might encounter hazardous debris. Since 2006 two new moons have been discovered near Pluto but it's unknown what other obstacles might be in orbit around it.



Saturn's largest moon Titan has an environment rich in organic compounds

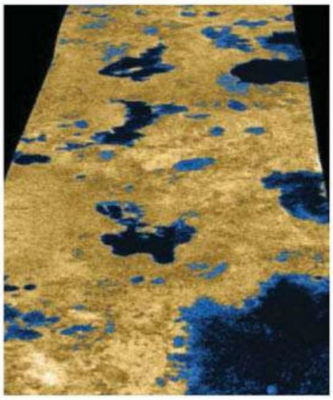
Boat-probe to explore Titan's lakes

NASA plans to set sail for the methane oceans of Saturn's largest moon

Forget orbiters and surface rovers like Cassini-Huygens, it's all hands on deck as boats could be the new means of exploring Saturn's largest moon, Titan, according to scientists whose adventurous proposal could be just what is needed to explore the network of seas, lakes and rivers on the smog-enshrouded moon's Earth-like surface.

With the aim of taking scientific measurements over a period of six months to a year, the Titan Lake In-situ Sampling Propelled Explorer, dubbed TALISE for short, will travel along Titan's liquid methane-drenched northern hemisphere with the help of wheels, paddles and screws after a splash-landing into the middle of the extensive lake Ligeia Mare; the largest body of liquid closest to the moon's north pole. While Titan is too cold to support life as we know it, its environment is rich in organic compounds along with hydrogen cyanide – the building blocks of life on our very own planet.

"The main innovation in TALISE is the propulsion system," explains team member Igone Urdampilleta, who is currently based at the engineering and technology group, SENER, where the concept is currently in the first stages of being developed in partnership with Centro de Astrobiologia in Madrid, Spain. "This allows the probe to move, under control, from the landing site, to the closest shore. The displacement capability would achieve the obtaining of liquid and solid samples from several interesting, scientific locations on Titan's surface such as the landing place, along the route towards the shore and finally at the shoreline." ■



Scientists believe that boat-probe TALISE would be a good choice in exploring the lakes of Titan

Galileo to rival US sat nav

Euro network completes first stage

Hot on the heels of the Americans, the Europeans have launched the final two spacecraft in the first stage of their multibillion-euro satellite navigation system, now known as Galileo, which has been tipped to rival the US's Global Positioning System (GPS). Made by Astrium and Thales Alenia Space, the system promises real-time positioning and unprecedented accuracy compared to its American counterpart.

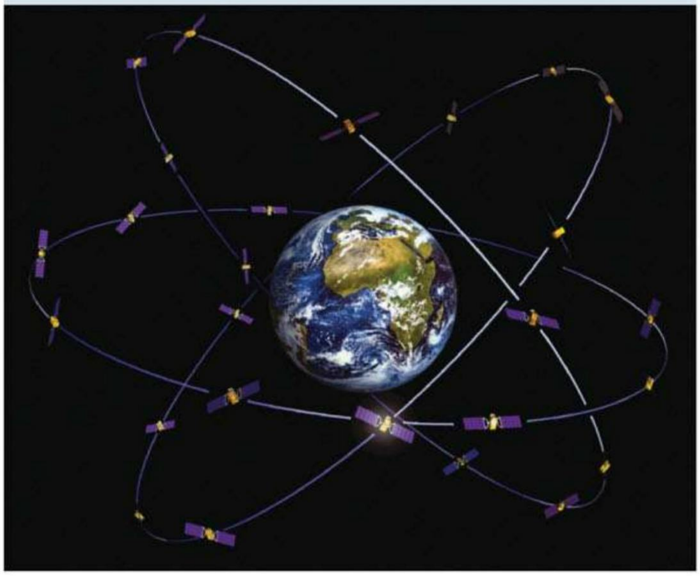
The third and fourth satellites, which were launched in October on board a Russian Soyuz rocket into a 23,250km (14,450-mile) high orbit, have now joined the initial two spacecraft that were blasted into an Earthly orbit in 2011.

While scientists on the project, jointly owned by the European Commission and the European Space Agency (ESA), aim to send some 30 satellites to join the quartet in the next decade or so, engineers must now run tests to check every aspect of Galileo's design. "Of course, these four satellites will [only] be visible during intermediate periods of time," says head of Galileo System Services, Marco Falcone at the ESA. "But from now on, receiver manufacturers will be able to start testing the system and preparing for Galileo services."

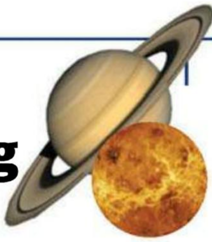
However, while only four satellites are required for smartphone users, fans of the sat nav will not be able to get the full benefits of Galileo just yet – at least not until 2015, when hopefully there will be enough spacecraft in orbit for users to realise the system's true capabilities.

With the potential to deepen and extend high-value markets already initiated by GPS, the first of Galileo's remaining spacecraft will be launched next year. ■

Galileo will enable Europe to become a major partner in setting up a civilian satellite service



What's happening in space...



NOVEMBER

20 ◐ QUARTER MOON

27 ○ FULL MOON

28

Venus and Saturn

These two planets will be within one degree of each other in the eastern morning sky.

DECEMBER

1

Antares lifts off

At some point in December, the much-delayed Orbital Sciences Antares rocket will finally launch the Cygnus spacecraft.

6 ◐ QUARTER MOON

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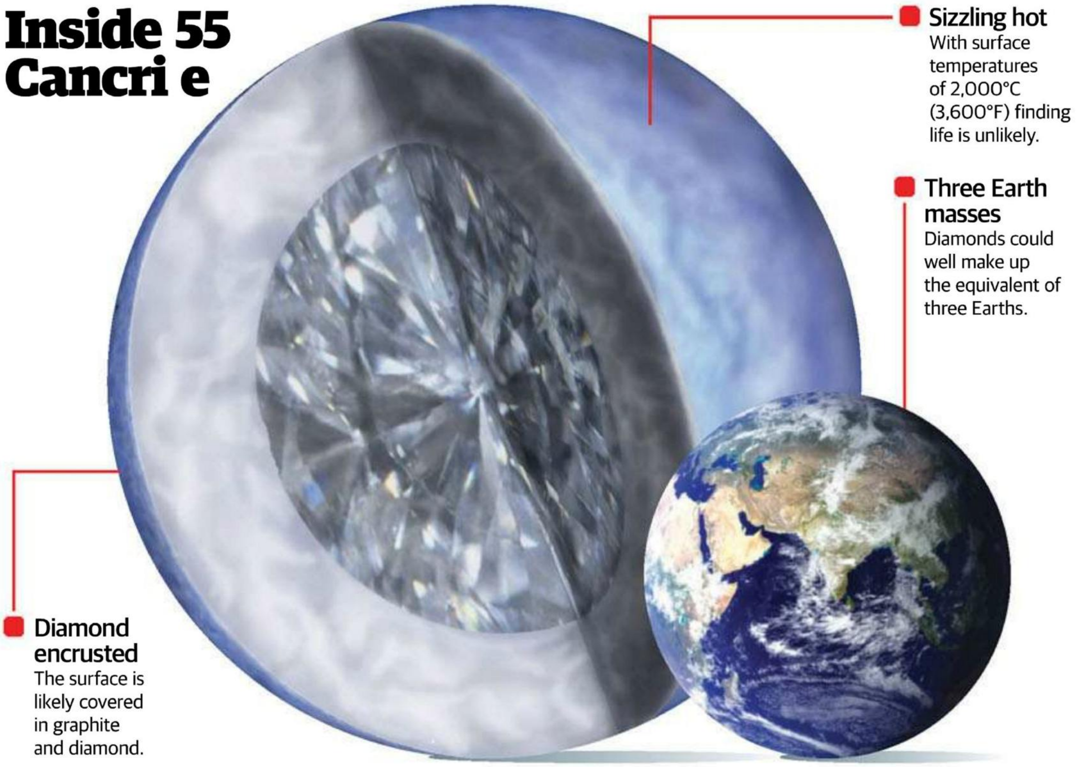
Inside 55 Cancri e



Sizzling hot
With surface temperatures of 2,000°C (3,600°F) finding life is unlikely.

Three Earth masses
Diamonds could well make up the equivalent of three Earths.

Diamond encrusted
The surface is likely covered in graphite and diamond.

Diamond twice the size of Earth found in space

Astronomers discover new carbon-rich exoplanet that redefines cosmic bling and sizzles at a blistering 2,000°C

They say diamonds are a girl's best friend but the possible discovery of a diamond-encrusted exoplanet twice the size of Earth could have just trumped the must-have accessory, according to research led by Yale University. The sought-after jewel is thought to take up at least a third of the planet's mass, the equivalent of three Earth masses, dwarfing any diamond ring.

"This is our first glimpse of a rocky world with a fundamentally different chemistry to Earth," says Yale postdoctoral researcher Nikku Madhusudhan, lead author of a paper accepted for publication in *Astrophysical Journal Letters*. "The surface of this planet is likely covered in graphite and diamond rather than water and granite."

The planet, dubbed 55 Cancri e, has a mass almost eight times greater than our own planet and hugs its parent star, Sun-like 55 Cancri A, tightly on a nimble orbit that lasts a mere 18 hours. Due to its proximity to its star, the super-Earth's surface reaches sizzling temperatures of over 2,000 degrees Celsius (3,600 degrees Fahrenheit), meaning that chances of finding life on 55 Cancri e are incredibly slim.

Uncovering a distant world brimming with carbon, the core element of diamond and graphite, means that our ideas of what exoplanets are made of has changed dramatically. "The identification of a carbon-rich super-Earth means that distant rocky planets can no longer be assumed to have chemical constituents, interiors, atmospheres, or biologies similar to those of Earth," explains Madhusudhan. "The discovery also opens new avenues for the study of geochemistry and geophysical processes in Earth-sized alien planets." ●

13 NEW MOON

13 **Geminids meteors**
One of the best meteor showers of the year, the Geminids produce up to 60 meteors per hour at their peak.

15 SPACEX **New cargo mission**
SpaceX will launch the second Dragon cargo mission to the ISS after the success of the first.

20 QUARTER MOON

22 **Ursids meteors**
Up to ten meteors per hour will be visible during the Ursids meteor shower.

28 FULL MOON

*All dates are subject to change

Apps OF THE MONTH

Essential space-related apps

Space Communications and Navigation: NetworkKing

For: iOS
Price: Free

This app from NASA lets you interactively build and upgrade a communications network around Earth to support satellites and interplanetary spacecraft. It's fun and it also teaches you about how mission communication works. ●

Space Junk Pro

For: Android/iOS
Price: £2.99/$4.99

This astronomy app is one with a difference. It focuses on objects that are in orbit around Earth, allowing you to track any man-made satellite you like and find it in the night sky. Of course, it also points out planets, stars and constellations. ●

Spacecraft 3D

For: Android
Price: Free

This awesome augmented reality app from NASA lets you observe and study a variety of spacecraft, from the Hubble Space Telescope to Cassini, in a 3D environment using your device's camera. It's just fantastic, so make sure you check it out. ●

ISS Detector

For: Android
Price: Free

If you've ever wanted to track and see the International Space Station in the night sky, this is a great app to download. Not only will it show you when the ISS is passing overhead, but it'll also point out other satellites as well. ●

NASA's Greatest Achievements

Written by Jonathan O'Callaghan

From the Moon landings to the Mars Science Laboratory, discover the triumphs of the world's greatest space agency

For over five decades NASA has been at the forefront of space science and exploration, launching hundreds of missions to further our understanding of Earth, the Solar System and beyond. Whittling down its multitude of accomplishments to just a handful of great achievements is no easy task, but we've chosen the ten missions and programmes that not only returned groundbreaking scientific data and images, but also those that inspired further missions and provided the framework for additional endeavours that would ensure NASA remained top of the pile. Read on to find out the missions that advanced our means of space science and exploration forever. ■

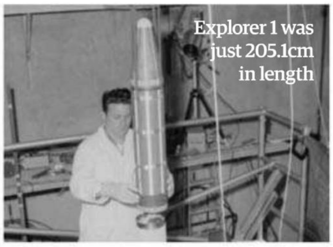
First scientific experiments in space 1958

On 4 October 1957, Russia stunned the world with its launch of Sputnik 1, the first man-made satellite to ever reach space. America was shocked, and the space race had begun.

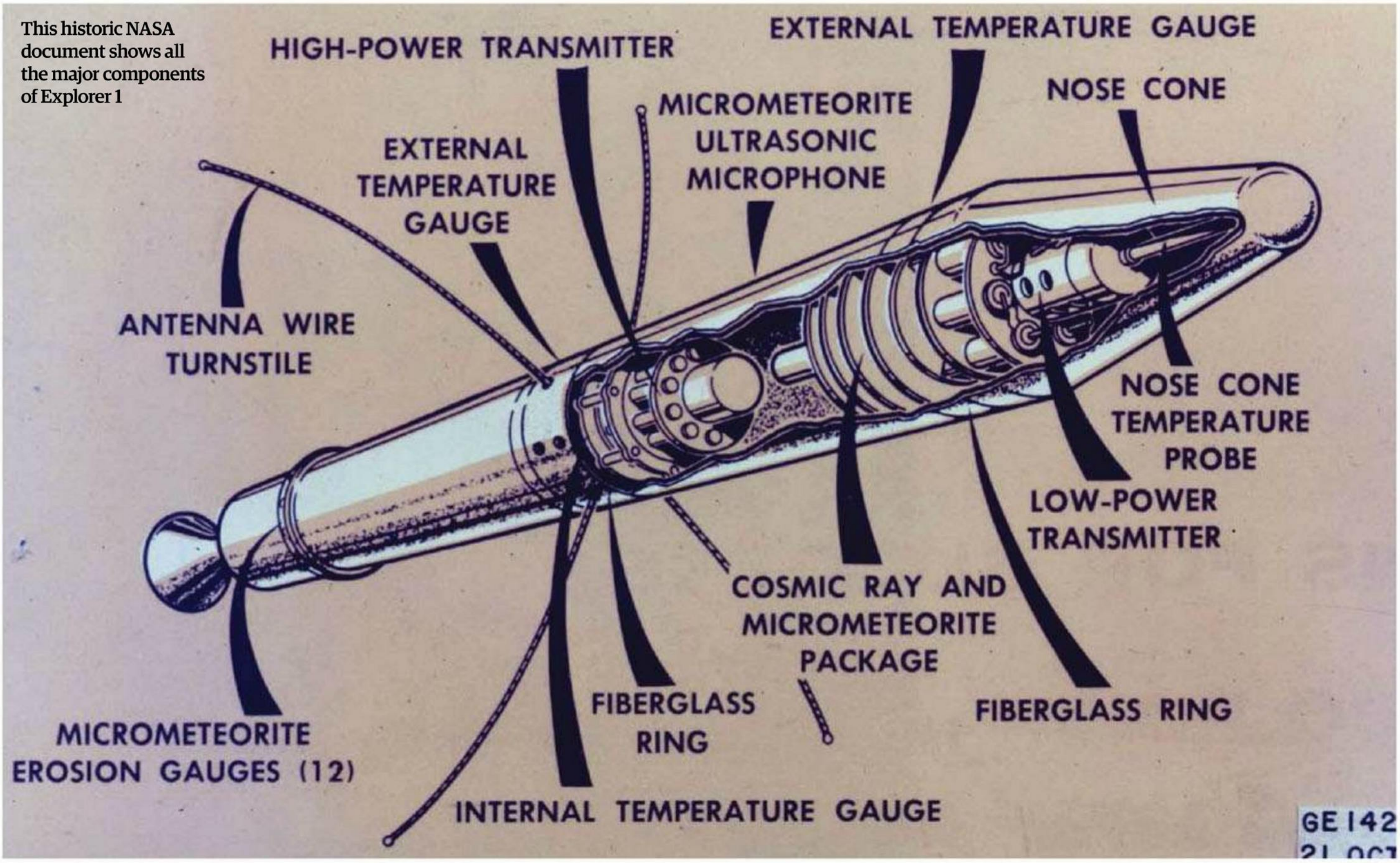
At the time, America's space agency was known as NACA (National Advisory Committee for Aeronautics). Working in tandem with the US Air Force, it devised a groundbreaking series of spacecraft known as the Explorer Program that would launch America into the space race.

The first of these spacecraft was Explorer 1, launched on 1 February 1958, which performed the first scientific experiments in outer space. The launch was timed to coincide with the International Geophysical Year, a celebration of the end of frosty relations between the East and West during the Cold War, although the Cold War would continue for many years after.

Although it was beaten to the accolade of first satellite in space by Russia, America was still able to carry out some groundbreaking science in suborbit that Sputnik 1 could not match. Explorer 1 truly signified the birth of NASA, and provided the groundwork through which the world's greatest space agency would become so great. ■


Explorer 1 was just 205.1cm in length

Explorer 1 weighed just 13.97kg compared to 83.6kg for Sputnik 1


This historic NASA document shows all the major components of Explorer 1

HIGH-POWER TRANSMITTER
EXTERNAL TEMPERATURE GAUGE
NOSE CONE
MICROMETEORITE ULTRASONIC MICROPHONE
EXTERNAL TEMPERATURE GAUGE
ANTENNA WIRE TURNSTILE
NOSE CONE TEMPERATURE PROBE
LOW-POWER TRANSMITTER
COSMIC RAY AND MICROMETEORITE PACKAGE
FIBERGLASS RING
FIBERGLASS RING
MICROMETEORITE EROSION GAUGES (12)
INTERNAL TEMPERATURE GAUGE
GE 142
21 OCT

The control room monitors the flight of Freedom 7

First American in space 1961

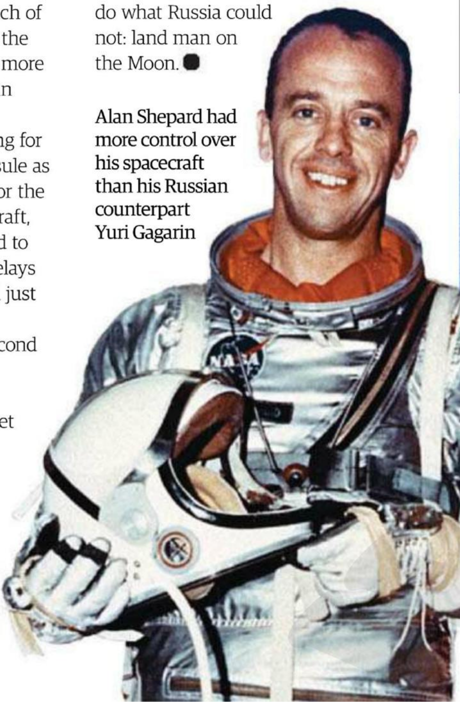
After stunning the world with its launch of Sputnik 1 in 1957, the Soviet Union left the world in awe once again when, on 12 April 1961, cosmonaut Yuri Gagarin launched into space aboard Vostok 1 and became the first human to ever enter outer space. Freedom 7 was NASA's answer to this Soviet milestone.

The space race between the Soviet Union and America had developed almost into an arms race, with each nation striving to prove who had the most muscle. Therefore, the launch of Vostok 1 was a major setback for the newly formed NASA, and all the more so because it almost had a man in space before Gagarin.

Alan Shepard had been training for a mission aboard a Mercury capsule as one of seven astronauts picked for the Mercury programme. His spacecraft, dubbed Freedom 7, was expected to fly early in 1961 but a series of delays meant that it didn't take off until just over three weeks after Gagarin.

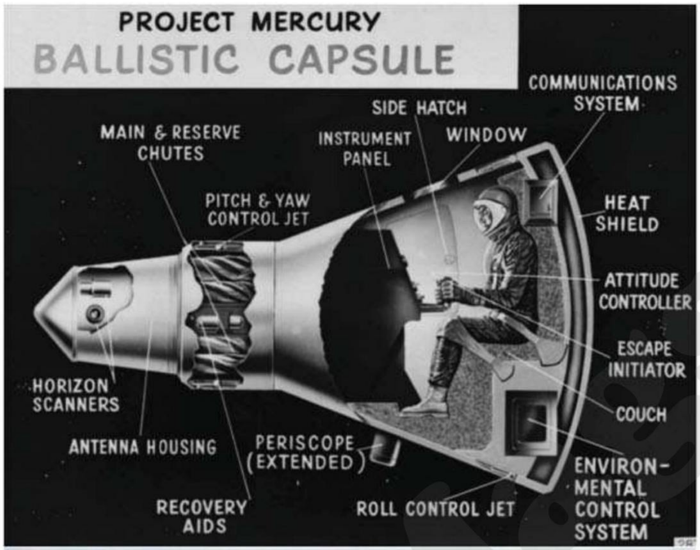
However, despite being the second human into space, Shepard had a much greater degree of control over his spacecraft than his Soviet counterpart. The entire flight lasted just 15 minutes, and Shepard reached an altitude of 187.5 kilometres (116.5 miles) before returning to Earth in a splashdown near Florida. He successfully tested the reaction control system, a series of thrusters that allowed him to manoeuvre in space, and he also observed the Earth.

Freedom 7 was a huge accomplishment for NASA. It proved to the world that it was well and truly in the space race with the USSR and although at the time it seemed to be further behind, it would be only eight years before the success of the six Mercury missions provided NASA with the knowledge and impetus to do what Russia could not: land man on the Moon. ●

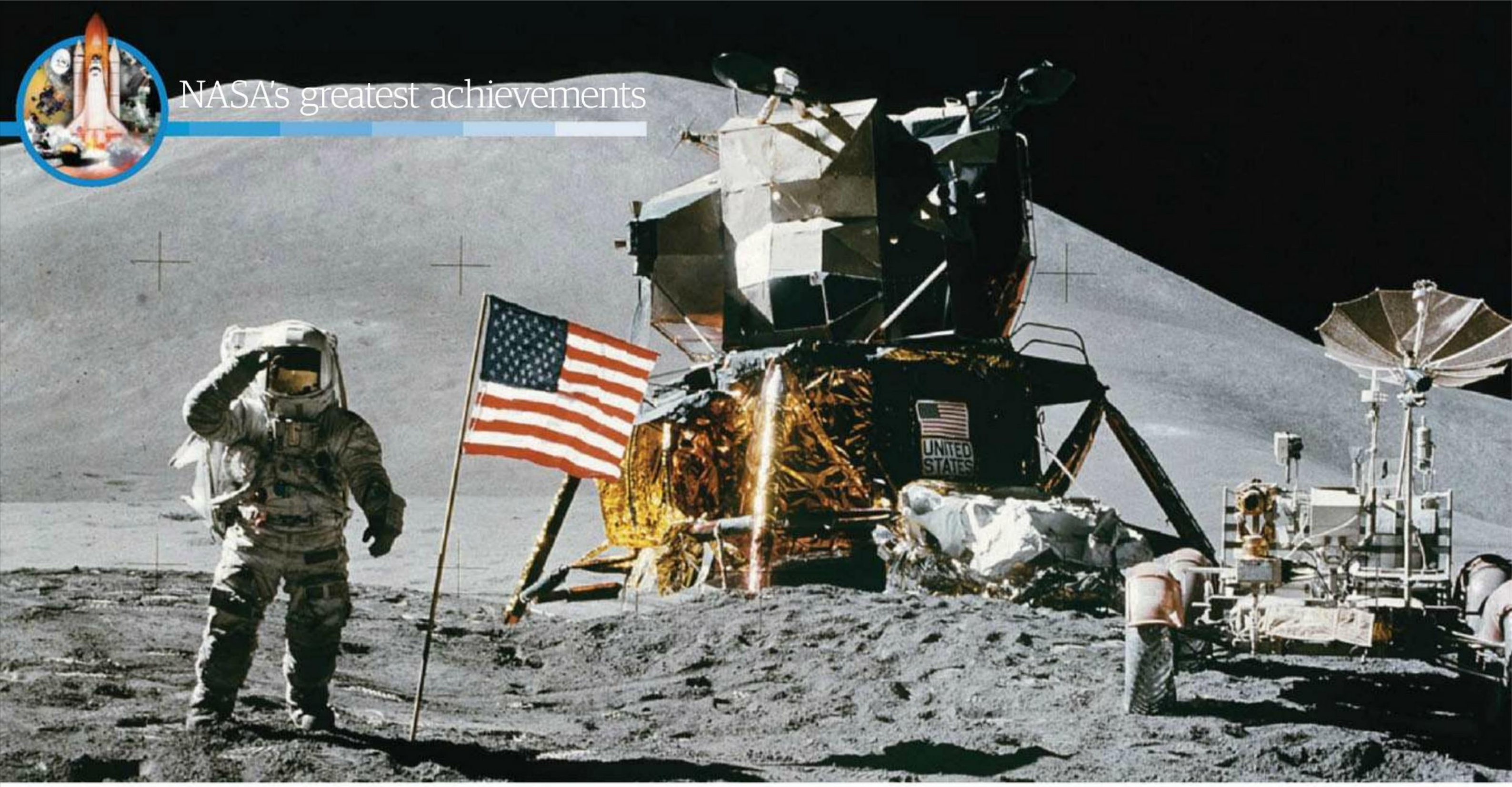


Alan Shepard had more control over his spacecraft than his Russian counterpart Yuri Gagarin

The interior of the Mercury capsule was cramped but provided the pilot with a degree of manual control



Alan Shepard splashed down off the coast of Florida on 5 May 1961 just over 15 minutes after launching



Landing men on the Moon 1969-72

On 12 September 1962, during a speech in Texas, President John F Kennedy outlined his plan for NASA to send humans to the Moon by the end of the Sixties: "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard."

It was a gauntlet NASA would gladly accept. Working on the success of the Mercury missions, and then perfecting orbital technologies from the following Gemini spacecraft, NASA finally had a vehicle that was capable of taking two humans to the lunar surface (and one to lunar orbit) by the late Sixties: the Apollo spacecraft.

It was unique in its design and employed many of the rendezvous techniques that had been perfected in earlier missions, which were vital in attaching the Command and Service Module to the Lunar Excursion Module in Earth orbit for transportation to the Moon. That's not to say there weren't tragedies, however. The loss of the Apollo 1 crew in 1967 during a routine test was a harsh reminder of how perilous such an endeavour was.

Nonetheless, NASA marched on. The first of the manned Apollo spacecraft to orbit the Moon was Apollo 8 in December 1968, followed by a 'dry run' for a lunar landing with Apollo 10. Then, on 16 July 1969, Neil Armstrong, Buzz Aldrin and Michael Collins launched on their way to the Moon. The former two set foot on the surface at 02:56 UTC on 21 July 1969, returning to Earth on 24 July. NASA had beaten Russia to the Moon, and in doing so had won the space race.

Buoyed by the success of Apollo 11, and the huge public interest, NASA was given the go-ahead to launch the remaining missions. Apollo 12 spent just over 31 hours on the surface, while Apollo 14 was there two hours longer. Apollo 15 was the first mission to use a lunar rover on the surface, Apollo 16 spent almost three days on the surface, and, finally Apollo 17, after three days on the Moon, ended the lunar missions. Sandwiched in between all of these was the Apollo 13

> "There were plans for further missions to the Moon in the form of Apollo 18, 19 and 20"

The lunar crews

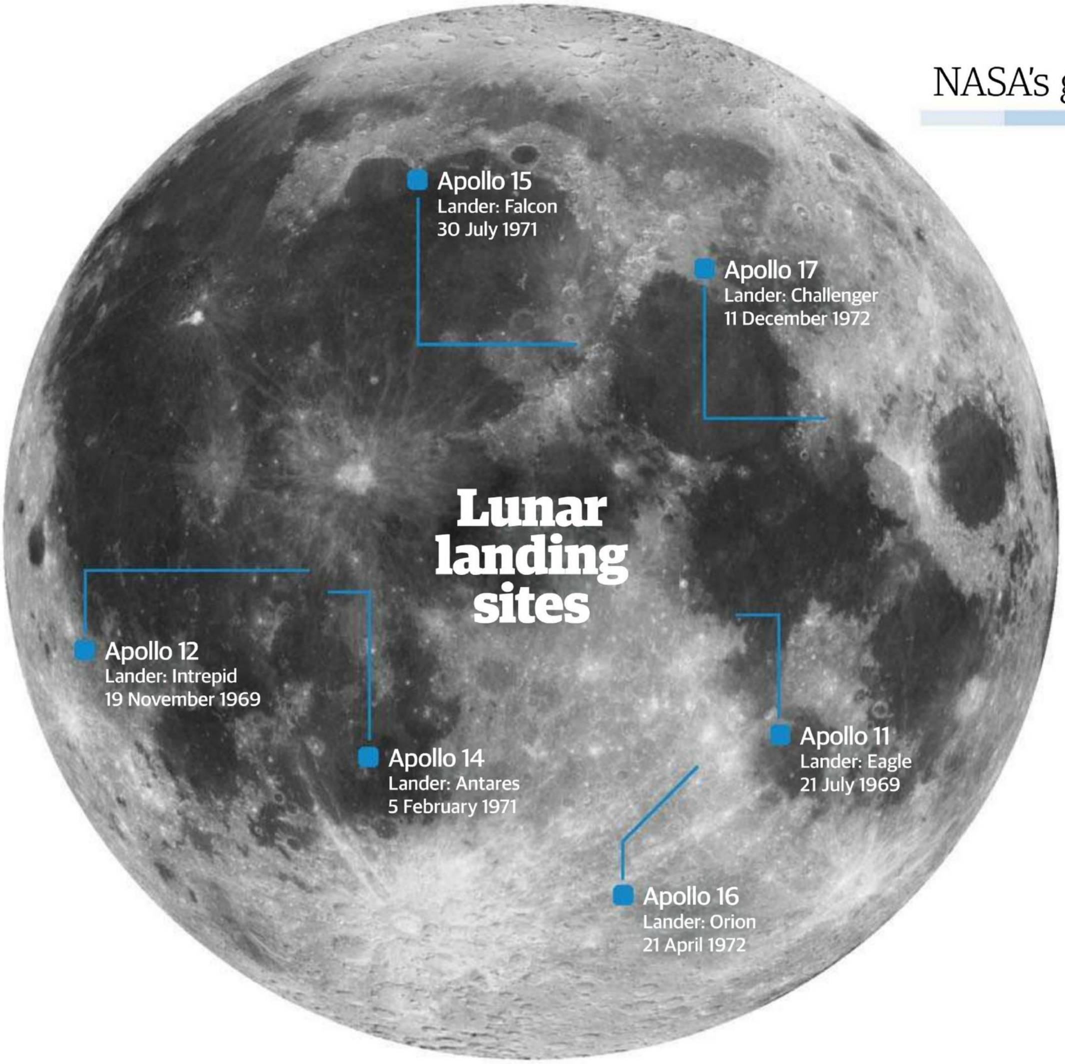
1969 Apollo 11
Neil Armstrong
Michael Collins
Buzz Aldrin

1969 Apollo 12
Pete Conrad
Richard Gordon
Alan Bean

1970 Apollo 13
Jim Lovell
Jack Swigert
Fred Haise

1971 Apollo 14
Alan Shepard
Stuart Roosa
Edgar Mitchell

Lunar landing sites



mission, which avoided catastrophe to safely return home despite not landing on the Moon.

There were plans for further missions to the Moon in the form of Apollo 18, 19 and 20. Sadly, the Saturn V rocket used to transport the Apollo spacecraft only had one further flight: to launch NASA's first space station, Skylab, into orbit. Amid dwindling public support the remaining Apollo missions were scrapped, and in their place the order was given to build a reusable spacecraft that had the goals of reducing the cost of reaching space and making it more accessible: the Space Shuttle. ■

NASA kept tabs on the Apollo missions, as with so many other space flights, from Mission Control

1971 Apollo 15
David Scott
Alfred Worden
James Irwin

1972 Apollo 16
John Young
Ken Mattingly
Charles Duke

1972 Apollo 17
Eugene Cernan
Ronald Evans
Harrison Schmitt

Saturn V

To carry astronauts out of low Earth orbit to the Moon, NASA needed a rocket bigger than anything that had ever launched before. Come in Saturn V, a rocket so big that Russia's attempts to emulate it ended in failure on four separate occasions.

The Saturn V was the pinnacle of a series of rockets designed by rocket scientist Wernher von Braun. It was preceded by several smaller iterations, including the Saturn I and Jupiter series of rockets, before undergoing its first successful test launch on 9 November 1967.

The rocket was huge, and it needed to be to carry astronauts such a great distance. It could take the equivalent of ten school buses to low Earth orbit and four to the Moon, while it used enough fuel to power a car around the world 800 times. In total 13 Saturn V rockets launched, taking all seven lunar missions to space and also launching NASA's first space station, Skylab, on the last launch of a Saturn V on 14 May 1973.

Since its final launch no rocket has even managed to come close to half the lifting power of this giant rocket, a testament to just what a technical marvel it was. Future rockets such as NASA's Space Launch System (SLS) will rival the Saturn V for the accolade of the world's most powerful rocket, but it will forever retain its status as the vehicle that took man to the Moon for the first time.

Rescuing Apollo 13 1970

Apollo 13 commander Jim Lovell catches up with the story after the crew's safe return

Despite the Apollo programme's six successful lunar landings, the story of Apollo 13 is perhaps only second in notoriety to that of Apollo 11. The successful return of this seemingly doomed crew of astronauts was testament to NASA's quick-thinking and technical expertise.

Apollo 13 was to be the third lunar landing, with touchdown planned to take place in the highlands of Fra Mauro on the Moon. The spacecraft launched in the afternoon of 11 April 1970 with apparently no problems, despite a minor engine malfunction on the Saturn V rocket, and just a few hours after launching it was on its way to the Moon as healthy as the rest of the Apollo missions had been.

However, just 55 hours into the mission on 13 April 1970, at a distance of 320,000 kilometres (200,000 miles) form Earth, something suddenly went wrong. Just 93 seconds after being asked by mission control to turn on the hydrogen and oxygen tank stirring fans, the astronauts heard a loud bang followed by fluctuations in power and firing of the spacecraft's thrusters.

The problem was the second oxygen tank of the Service Module, which had exploded following a short circuit in the wires to one of the stirring fans. With limited power available, and life-essential resources running out, the crew used the Lunar Module as a lifeboat. The possibility of landing on the surface of the Moon was now impossible, and the primary mission was aborted by lead flight director Gene Kranz (read more about him on page 98).

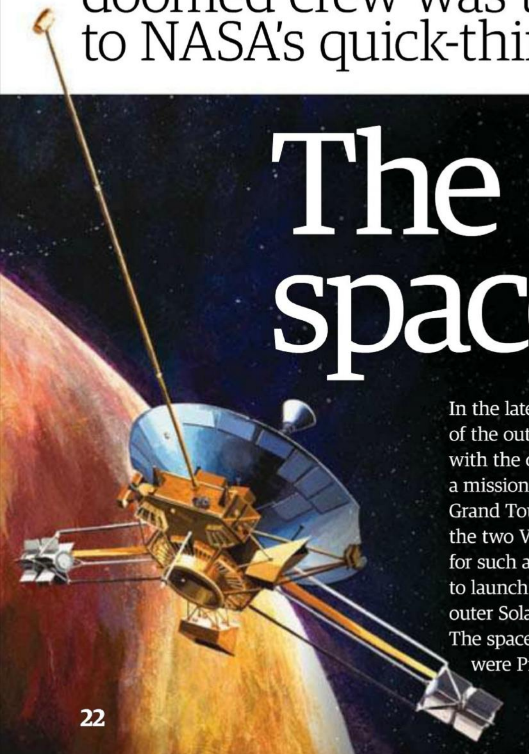
Owing to its proximity to Earth's satellite, the decision was made to swing Apollo 13 around the Moon to return it to Earth. Four days after the accident first occurred, and with survival hanging by a thread, the crew successfully splashed down on Earth on 17 April 1970. Their safe return was celebrated around the world, and the lessons learned from this mission allowed for the continued success of the next four lunar missions. ■

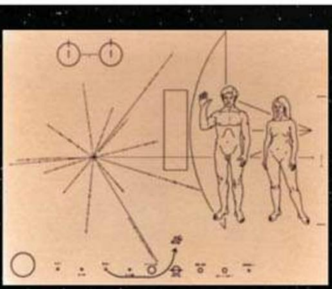
> "The return of this seemingly doomed crew was testament to NASA's quick-thinking"

The damaged Service Module; Below: Inside the Lunar Module during the journey back to Earth

Quick-thinking from mission control helped avert disaster for the crew

The first deep space probe 1972





In the late-Seventies a rare alignment of the outer planets provided NASA with the opportunity to carry out a mission known as the Planetary Grand Tour, which would later involve the two Voyager probes. To prepare for such an endeavour, NASA planned to launch two spacecraft into the outer Solar System for the first time. The spacecraft chosen for the task were Pioneer 10 and 11.

Pioneer 10 weighed 258kg (570lb) and had a 2.74m (8.9ft) dish acting as its central point for communications with Earth. Power was supplied by radioisotope thermoelectric generators. It was launched on 2 March 1972 with great speed. It passed by the Moon in just 11 hours, becoming the fastest man-made object of the time in the process. After ten days all of its instruments were activated and the crux of its mission was well and truly underway.

On 15 July 1972, Pioneer 10 became the first spacecraft to enter the asteroid belt. On 6 November 1973, it began taking images of Jupiter, revealing the gas giant in all its glory for the first time.

The intense radiation around Jupiter caused a few problems with the spacecraft, including the loss of

Mapping the inner Solar System 1971

While NASA was beginning serious preparations for the Moon landings, another series of spacecraft were busy proving just what this space agency could achieve, even in its infancy. The Mariner programme involved a number of near-identical spacecraft that would be sent to explore Venus, Mars and Mercury, something that, with the exception of the early Soviet Venera missions to Venus in the Sixties, no nation had yet done.

Unfortunately, the programme had a rough start. Mariner 1, intended to return communications from Venus, was destroyed just five minutes after taking off on 22 July 1962. Mariner 2 was able to complete the same mission when it launched on 27 August 1962, but the next mission, Mariner 3, also experienced a launch failure and was lost in 1964 on NASA's first attempt at a Mars flyby. Its successor, Mariner 4, managed to achieve a Mars flyby, though, the first spacecraft to do so.

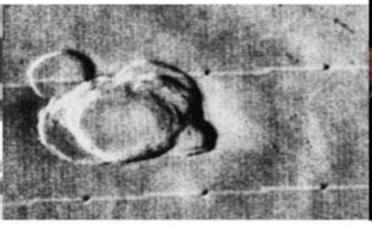
A series of further flybys of Venus and Mars were carried out, with mixed results, but the major accomplishment of the programme was Mariner 9. Launched on 30 May 1971 after the loss of its sister craft Mariner 8, it became the first spacecraft to enter a Martian orbit, or indeed the orbit of any planet other than Earth, in November 1971. Weighing almost 1,000 kilograms (2,200 pounds), Mariner 9 took extensive photography of the surface of Mars for the first time and also analysed its atmosphere.

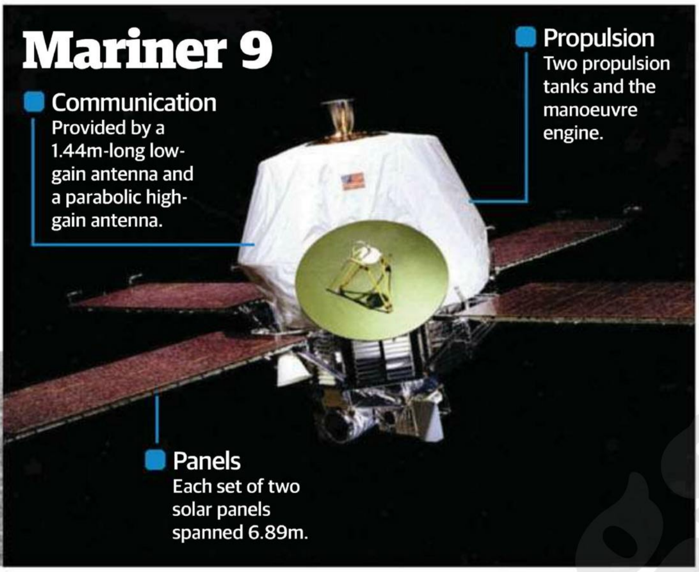
In total it returned over 7,000 images of Mars during its year-long mission before ceasing communications, although it will remain defunct in Martian orbit until 2022 when it will be pulled through the atmosphere and either burn up or crash into the surface. In honour of Mariner 9's achievements the Valles Marineris canyon on Mars, the largest known canyon in the Solar System, was named after it.

Mariner 9 was succeeded by Mariner 10, the first spacecraft to employ gravitational assist manoeuvres, and also Mariner 11 and 12. These latter two spacecraft were sent on missions to explorer the outer planets, including Jupiter and Saturn, and they are currently making their way out of the Solar System. You might know them by the new names they were given, however, as part of a new mission: Voyager 1 and 2, the Voyager programme.

The Mariner 9 mission control at JPL's facilities in California

Olympus Mons, photographed by Mariner 9, which took extensive images of Mars





Mariner 9

Communication
Provided by a 1.44m-long low-gain antenna and a parabolic high-gain antenna.

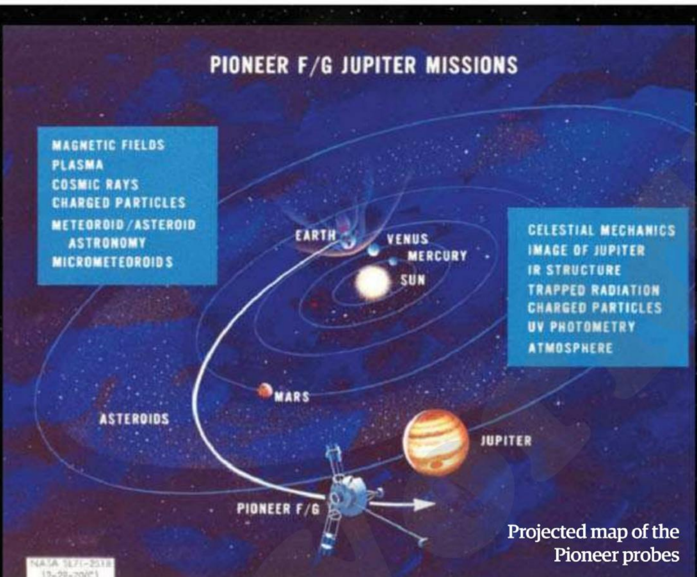
Propulsion
Two propulsion tanks and the manoeuvre engine.

Panels
Each set of two solar panels spanned 6.89m.

an image of Io and some close-ups of Jupiter. It did, however, return rudimentary images of Ganymede and Europa.

Pioneer 10's trajectory took it behind Io, relative to Earth, where it was able to measure the moon's atmosphere. It then escaped from the orbit of Jupiter and made its way towards the edge of the Solar System, crossing the orbits of Saturn and Uranus in 1976 and 1979 respectively.

The last communication with Pioneer 10 was on 23 January 2003, when it was at a distance of 12 billion km (7.5 billion miles) from Earth. It continues to coast into interstellar space and is heading in the direction of the star Aldebaran, 68 light years away. It will reach it over two million years from now, a lasting figure of one of NASA's great achievements.



Projected map of the Pioneer probes

Voyager

The final two vehicles in the Mariner programme, originally named Mariner 11 and 12, were reallocated as the sole spacecraft in the Voyager programme.

Launched in 1977, the Voyager probes are now on their way out of the Solar System. Their 35-year mission has seen them explore Jupiter, Saturn, Uranus and Neptune. Of the two, Voyager 1 is now the furthest man-made object from Earth at a distance 122 times greater than the Earth-Sun distance. The radio transmitters of both probes will operate until at least 2025.

01

02

03

04

The Shuttle: first reusable spacecraft

1981-2011

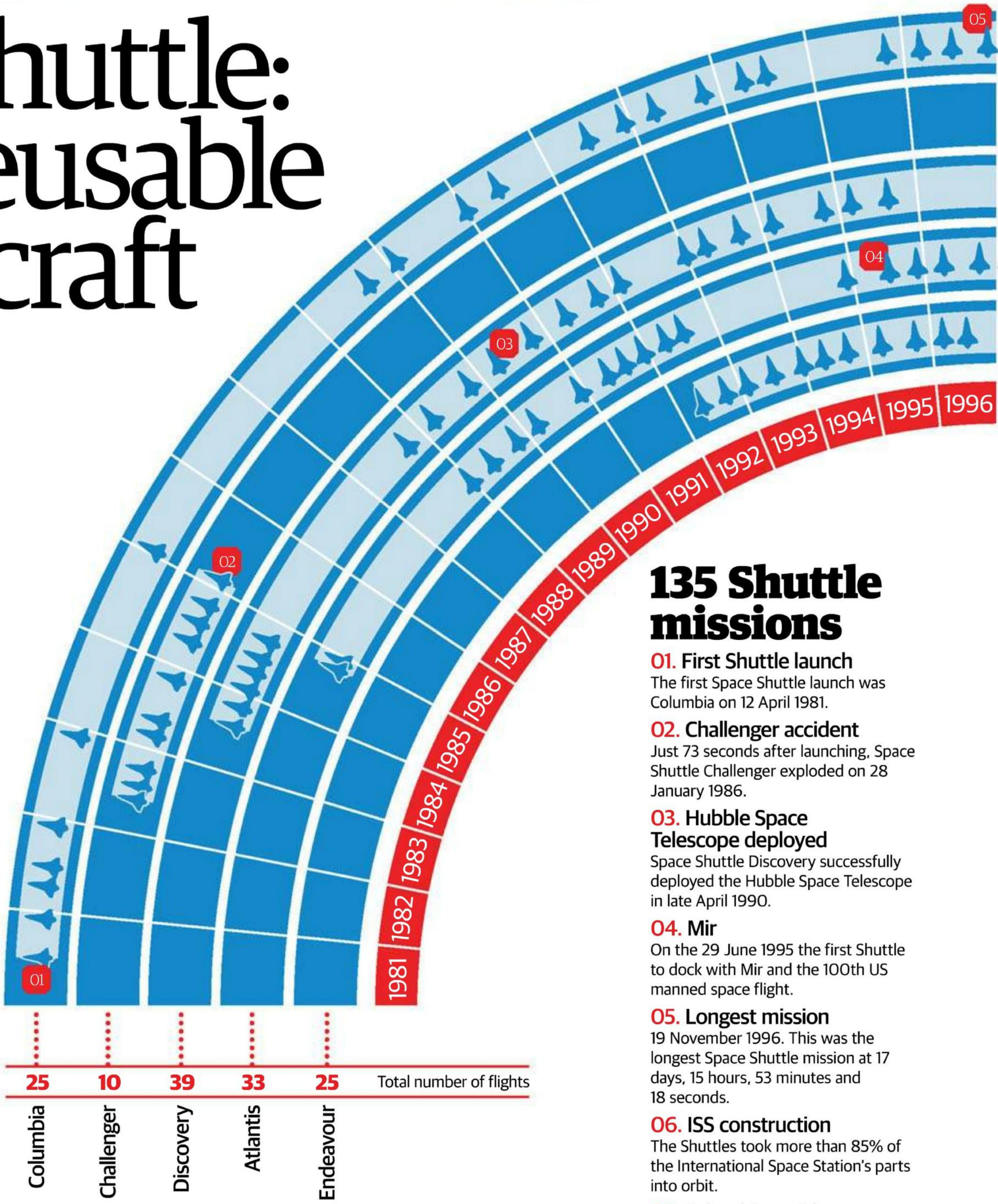
After the conclusion of the Apollo missions, NASA was reeling from the total cost of the programme (believed to be over $100 billion USD in 2010 money) and was tasked with finding a cheaper way to reach orbit.

The concept for a reusable space plane actually materialised even before the Apollo missions had begun. However, in 1969, it was President Nixon who gave the order for the development of what would become known as the Space Transportation System (STS), or Space Shuttle.

The idea of the Shuttle was to act as a sort of service ship. The spacecraft took off vertically with an expendable external tank and two recoverable solid rocket boosters. The seven-person vehicle could carry a variety of payloads into low Earth orbit as well as being able to fix satellites and telescopes in space.

Five Shuttles capable of going to space were built in total, with an additional sixth, Enterprise, only used for testing gliding and landing within Earth's atmosphere. Two of the Shuttles were sadly destroyed during and post launch, Challenger (1986) and Columbia (2003), both losing their entire crews in the process.

Despite these tragic accidents and various cost overruns, the Space Shuttle is without doubt one of NASA's greatest achievements. After an age where we'd witnessed rudimentary capsules take astronauts into space, it was fascinating to watch these glorious space planes take to the skies and perform tasks that no other spacecraft could. ●



> "Each shuttle was given an operational life span of ten years, to include 100 launches"

135 Shuttle missions

01. **First Shuttle launch**
The first Space Shuttle launch was Columbia on 12 April 1981.

02. **Challenger accident**
Just 73 seconds after launching, Space Shuttle Challenger exploded on 28 January 1986.

03. **Hubble Space Telescope deployed**
Space Shuttle Discovery successfully deployed the Hubble Space Telescope in late April 1990.

04. **Mir**
On the 29 June 1995 the first Shuttle to dock with Mir and the 100th US manned space flight.

05. **Longest mission**
19 November 1996. This was the longest Space Shuttle mission at 17 days, 15 hours, 53 minutes and 18 seconds.

06. **ISS construction**
The Shuttles took more than 85% of the International Space Station's parts into orbit.

07. **Columbia accident**
On 1 February 2003 Space Shuttle Columbia disintegrated as it re-entered Earth's atmosphere.

08. **Final launch of Shuttle**
Atlantis launched on the 135th and final Space Shuttle mission on 8 July 2011.

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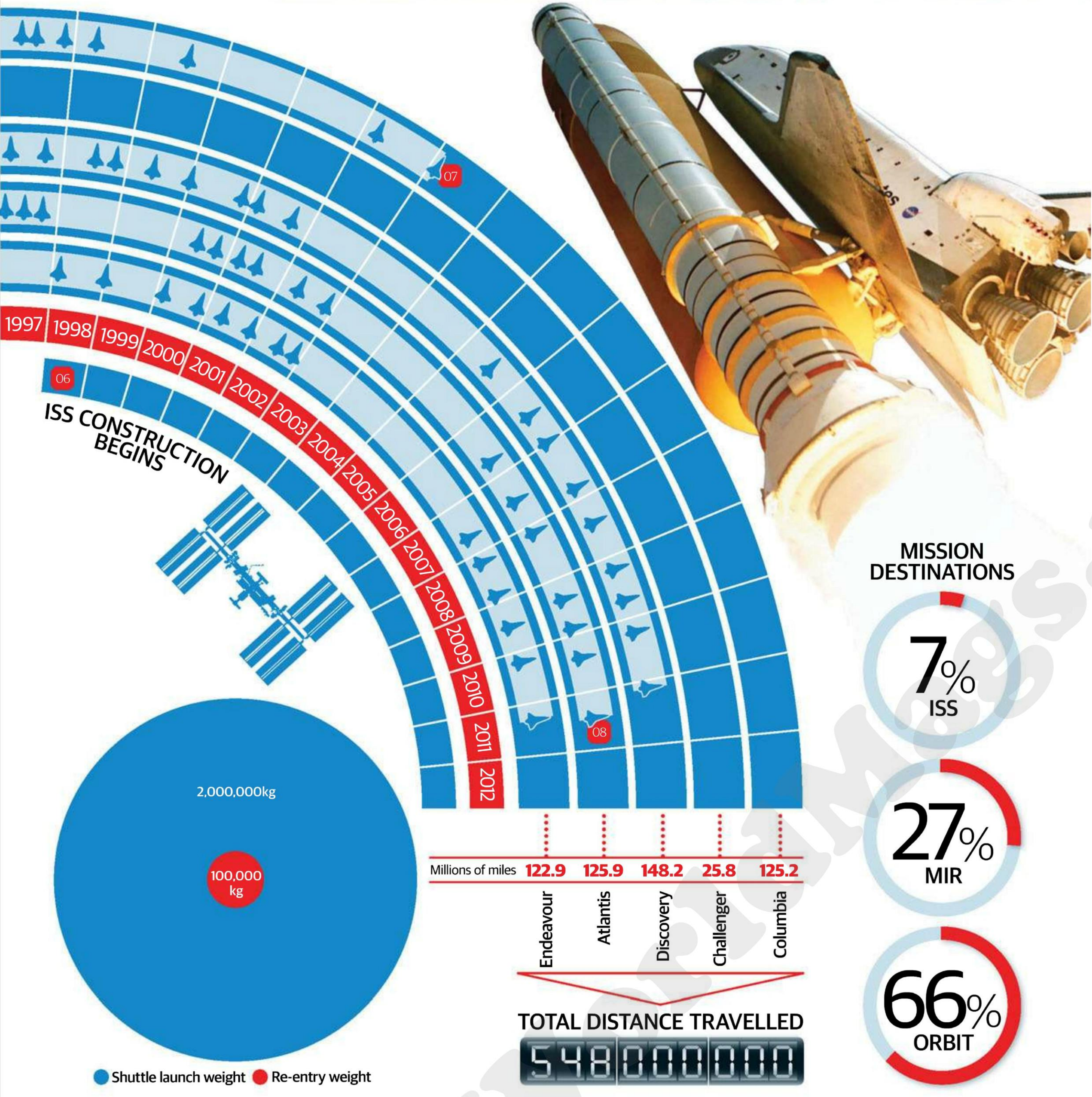
07
1997
1998
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2006
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2010
2011
2012
06
ISS CONSTRUCTION BEGINS
08
2,000,000kg
100,000 kg
Millions of miles
122.9
125.9
148.2
25.8
125.2
Endeavour
Atlantis
Discovery
Challenger
Columbia
TOTAL DISTANCE TRAVELLED
548000000
Shuttle launch weight
Re-entry weight
MISSION DESTINATIONS
7% ISS
27% MIR
66% ORBIT

Discovering the far reaches of space 1990

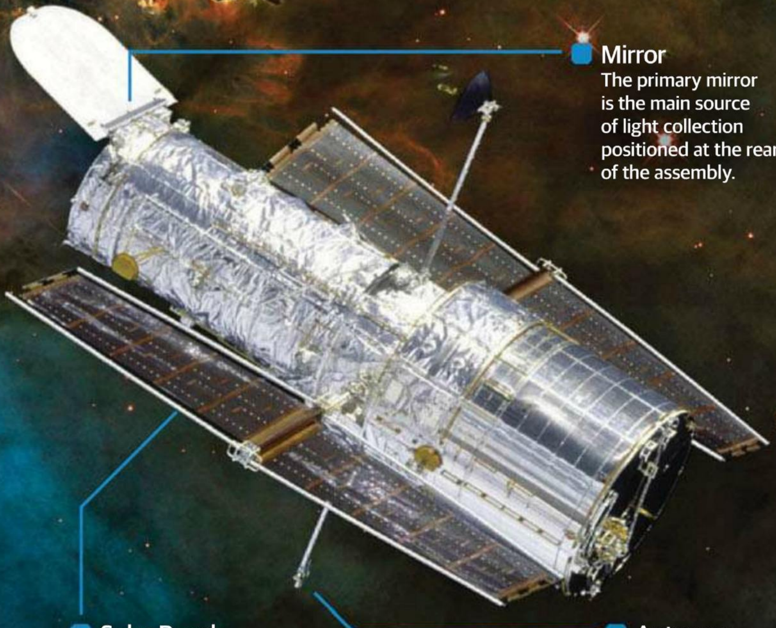
In 1968, NASA began developing plans for a space-based reflecting telescope, dubbed the Large Space Telescope (LST). While observatories had been sent to space before, the 3m (9.8ft) diameter of this telescope's mirror would be unsurpassed in size, offering unique views of the universe. However, one necessity of the telescope was that maintenance missions would be needed to prolong its lifetime in orbit, something made possible by the arrival of the Space Shuttle in 1981.

Funding did not arrive until 1978, with a provisional launch date of 1983 set. The name of the telescope was also changed to commemorate American astronomer Edwin Hubble, who had discovered that the universe is expanding in the 20th Century. Therefore, the LST became the Hubble Space Telescope (HST).

Amid rising costs and considerable delays, the HST finally looked like it would launch in late 1986. That was until the Space Shuttle Challenger accident that year brought the US manned space programme to a halt. Following the resumption of Shuttle flights in 1988, the HST finally launched on 24 April 1990.

In 2010 dollars the HST mission cost a total of $10 billion to build and launch, so it was imperative that the mission got off to a clean start. Unfortunately, a flawed mirror meant that the initial images were of poorer quality than they should have been. It was not until a Shuttle servicing mission in 1993 that the HST was ready to begin full operations.

Despite the setbacks, the HST is now the most successful space telescope of all time. It has taken hundreds of thousands of images and increased our understanding of the cosmos like no other telescope has. Among its notable discoveries it has observed distant supernovae, found evidence for an expanding universe, detected the first presence of planets outside the Solar System and much, much more. It has rightly earned its place in our list as one of NASA's greatest ever achievements.

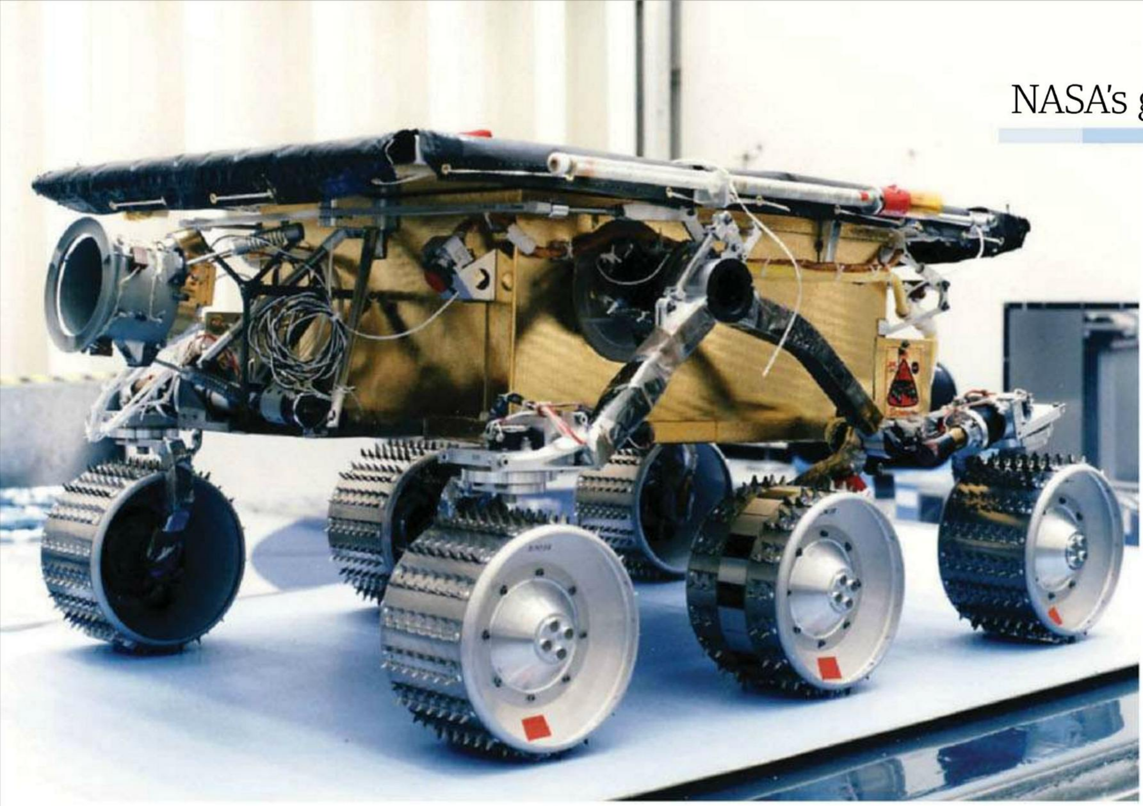


Mirror
The primary mirror is the main source of light collection positioned at the rear of the assembly.

Solar Panels
The large solar cells supply all of the 2,800 watts that Hubble requires.

Antennae
Astronomers use these to send Hubble orders and commands.

Operators man the controls for the Hubble telescope at NASA's Goddard Space Flight Center



Landing the first Mars rover 1997

After performing flybys and studying the Red Planet, it became apparent that Mars was one of the most fascinating places in the Solar System. With a topography bearing similarities to Earth and the possibility of once being a habitable environment, there were many secrets of Mars that NASA wanted to uncover.

The Sojourner rover, part of the Mars Pathfinder mission, was therefore an opportunity to explore the surface of Mars like never before. No rover had ever ventured across the surface and, while the Viking probes had already landed and performed analysis back in the Seventies, Sojourner would be a brand new and exciting venture.

Pathfinder used a revolutionary method to reach the Martian surface that would also be employed on NASA's next two rovers, Spirit and Opportunity. The craft parachuted through the atmosphere before bouncing across the surface in a giant system of air bags, coming to rest and allowing the Sojourner rover to escape on to the surface.

Launched on 4 December 1996, the Sojourner rover weighed just 10.5 kilograms (23.15 pounds) and was just 0.65 metres (25.6 inches) long. It landed on Mars on 4 July 1997 and operated until 27 September 1997.

Thanks to the 2 billion pieces of information returned by the stationary Mars Pathfinder lander and the Sojourner rover, which included a combined total of over 17,000 images, scientists gleaned a new insight into the possibly warm and wet past on Mars, providing an excellent incentive to return to the Red Planet with the Mars Exploration rovers and, more recently, Curiosity.

Never before had such a mission been attempted, and therefore it was a huge coup for NASA to succeed where others, including Britain and Russia, had and would fail. Pathfinder lived up to its name, providing the means through which future missions would be successful, but also performing groundbreaking science of its own. ■

Mars Pathfinder being prepared for launch by Jet Propulsion Laboratory workers

Mars rovers

4 Jul 1997

Sojourner
Sent back thousands of images of the Red Planet.

4 Jan 2004

Spirit
Spirit explored a possible former lake in the Gusev crater.

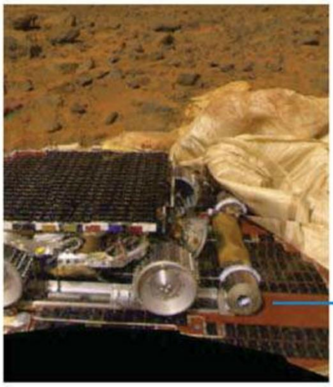
25 Jan 2004

Opportunity
Explored the Victoria and Endeavour craters.

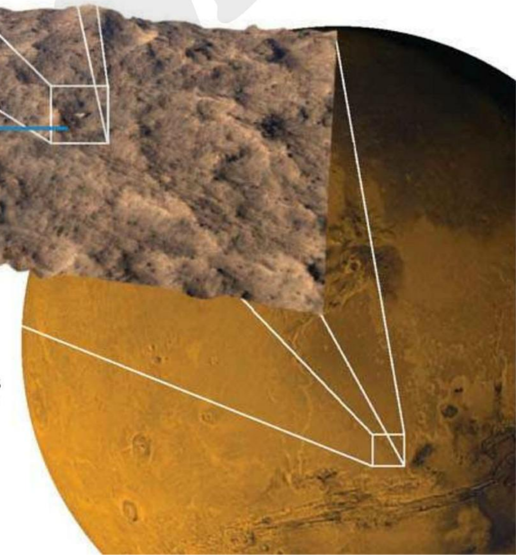
5 Aug 2012

Curiosity
Has a host of hi-tech instruments to study Mars like never before.

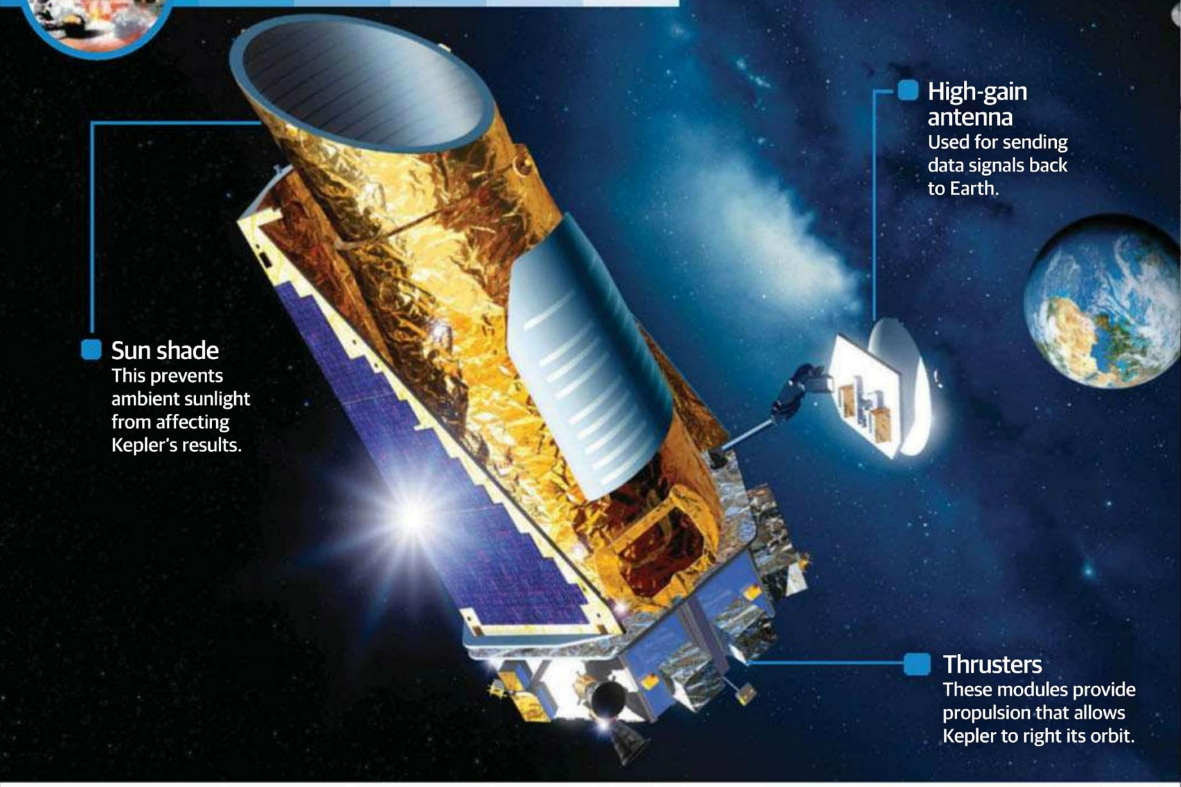
Landing site



Rocky planet
Scientists chose Ares Vallis because they found it to be a relatively safe surface to land on.

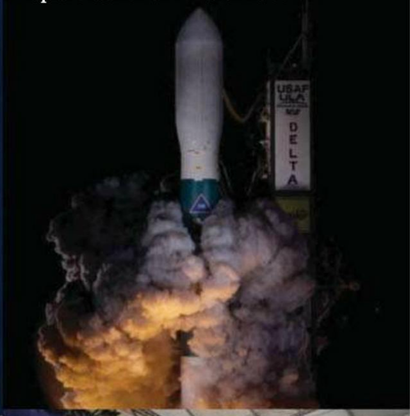


Ares Vallis
The landing site was an ancient flood plain in Mars's northern hemisphere called Ares Vallis.

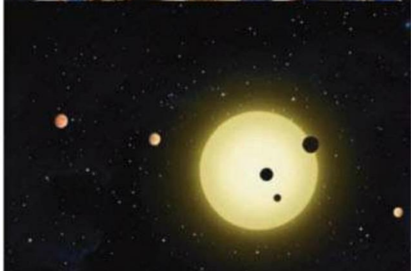

High-gain antenna
Used for sending data signals back to Earth.
Sun shade
This prevents ambient sunlight from affecting Kepler's results.
Thrusters
These modules provide propulsion that allows Kepler to right its orbit.

Kepler was built by Ball Aerospace in Boulder, Colorado

Kepler's launch on 7 March 2009



Crowds gather to watch the launch of Kepler on a Delta II rocket


Kepler uses the transit method to detect exoplanets around stars

Finding new exoplanets 2009

150 million kilometres (93 million miles) behind Earth in its orbit lies the Kepler Space Telescope, a remarkable spacecraft that has helped us to increase our knowledge and understanding of planets outside the Solar System, known as exoplanets.

The hunt for exoplanets is a relativity new area of astronomy. When Kepler was launched on 7 March 2009, we knew of just a few of these planets. Fast-forward to today and we now know of hundreds of exoplanets ranging in size from Earth-like to super-Earth, with masses several times that of our own world, and its all thanks to Kepler.

Named after 17th Century German astronomer Johannes Kepler, this telescope was designed to hunt for planets like our own in the region of the Milky Way near us. The telescope has just one instrument, a photometer to measure the brightness of distant stars, but that's all it needs. By looking out for dips in the brightness of a star, Kepler can deduce whether a planet (or planets) is in orbit or not.

The initial discoveries, as expected, were more of the large gas giant planets in extremely close orbits to their host star. Further observations, however, have begun to return new and exciting extrasolar systems, from the Gliese 581 planetary system to the worlds Kepler-20e and Kepler-20f.

The mission was recently extended to 2016 to give Kepler more time to continue its hunt for new worlds. In such a new area of astronomy, the Kepler Space Telescope has performed groundbreaking science. Future telescopes, like the James Webb Space Telescope in 2018, will continue the work laid down by Kepler. ■

5 key planet discoveries

Kepler-10b

This was the first rocky planet to be found by Kepler, an important discovery in its continuing search for a world like our own. It is 1.4 times the size of Earth.

Kepler-20e

This was the first planet smaller than Earth to be found orbiting a Sun-like star. Although it is extremely hot and likely uninhabitable, its discovery was important in the hunt for Earth analogues.

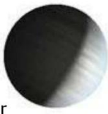
Kepler-22b

This planet, first noticed in May 2009, was the first to be found in the habitable zone of a Sun-like star. It is over twice the size of Earth and located about 600 light years away.

Kepler-16b

This fascinating, Tatooine-like world was the first planet found to be orbiting two stars, known as a circumbinary planet. It is cold, gaseous and not thought to harbour life.

Kepler-47c



This circumbinary planet was found along with another planet, Kepler-47b, the first multiple planet circumbinary system to be discovered. It is within its host star's habitable zone.

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WorldMags

The world's largest telescope array

This collection of giant radio dishes will create a 10-mile-wide telescope to give unsurpassed views of the cosmos

High in the Atacama Desert of northern Chile, construction is nearing completion on what will be the biggest telescope array the world has ever seen. Composed of 66 separate radio telescopes, the Atacama Large Millimeter Array (ALMA) is a mammoth project that will allow us to observe the universe with vision ten times sharper than the Hubble Space Telescope.

The exact location of this huge project is the Chajnantor plateau at an altitude of 5,000 metres (16,400 feet). It is an international partnership between Europe, the US, Canada, East Asia and the Republic of Chile. With a price tag over a billion dollars it is also the most expensive ground-based telescope under construction.

Work on ALMA started in 2004 and its first scientific observations with some of the antennas that had already been positioned began in late 2011. The operational capabilities of this array are unique. Each of the 66 antennas can be moved across the desert using giant transporter vehicles, allowing the array to be configured for the type of observations it will do. At its widest, the array will span 16 kilometres (ten miles), allowing astronomers to glean wide-angle images of the night sky. At its narrowest, just 150 metres (490 feet), much more focused views of a specific object can be taken.

All of the antennas can be trained to point in the same direction for ultimate focus, known as interferometry, or they can each observe a different portion of the night sky to simultaneously study various cosmic features. 54 of the high-precision antennas are 12 metres (40 feet) in diameter, while 12 of them are seven metres (23 feet).

ALMA has an impressive range of possible applications. It will be used to study the chemical and physical compositions of interstellar dust and gas and observe some of the earliest and most distant galaxies in the universe, among much more. This is thanks to its use of submillimetre astronomy, which allows it to observe areas that would otherwise appear dark in visible light.

ALMA is due for completion in 2013. It will hold the accolade of largest telescope array until the completion of the Square Kilometre Array in 2024.

ALMA is set to be the largest telescope array until the Square Kilometre Array's completion in 2024

The maximum distance between antennas can vary from 150m (490ft) to 16km (ten miles)

Asteroid mining

Could hordes of unmanned robots extract valuable resources from floating space rocks near Earth?

Surrounding the Earth are hundreds of mineral-rich rocks, or asteroids, containing what might be billions or even trillions of dollars worth of resources, including metal and water. The possibility of tapping into these unclaimed goldmines has been a long-held dream, but it might be one that is now moving closer to reality.

Just one asteroid could contain more precious metal than has ever been used by humanity, and enough water to power fleets of rockets. But who's going to stump up the cash to mount an expedition to an asteroid that, for one, could fail, and two, would require huge infrastructure?

One company is Planetary Resources. A conglomeration of entrepreneurs and technicians which includes film director James Cameron, this ambitious venture will be the first to aim to mine asteroids and return their valuable resources to Earth or use them in space.

With current technologies, the cost of returning a significant sample from an asteroid to Earth, let alone mining resources for use in space, far outweighs the comparative cost of mining said resource on Earth and using it here or sending it to space.

So, what's the point in doing it then? "The vision of Planetary Resources is to make the resources of space available to humanity both in space and here on Earth," said Planetary Resources co-founder Peter Diamandis in April 2012.

That would surely have to be the goal of any asteroid mining endeavour, one of exploration rather than money-driven, although the potential pay-off is huge. The key will be the method that is used. There are several ideas of how it could be done.

We'll take a look at this from the plan devised by Planetary Resources. Its first step is to carry out a series of small missions to lay the groundwork for a future visit to an asteroid. This will begin in 2013 with a small telescope called Arkyd 101 that will search for suitable asteroids. There will be about 20 of these telescopes.

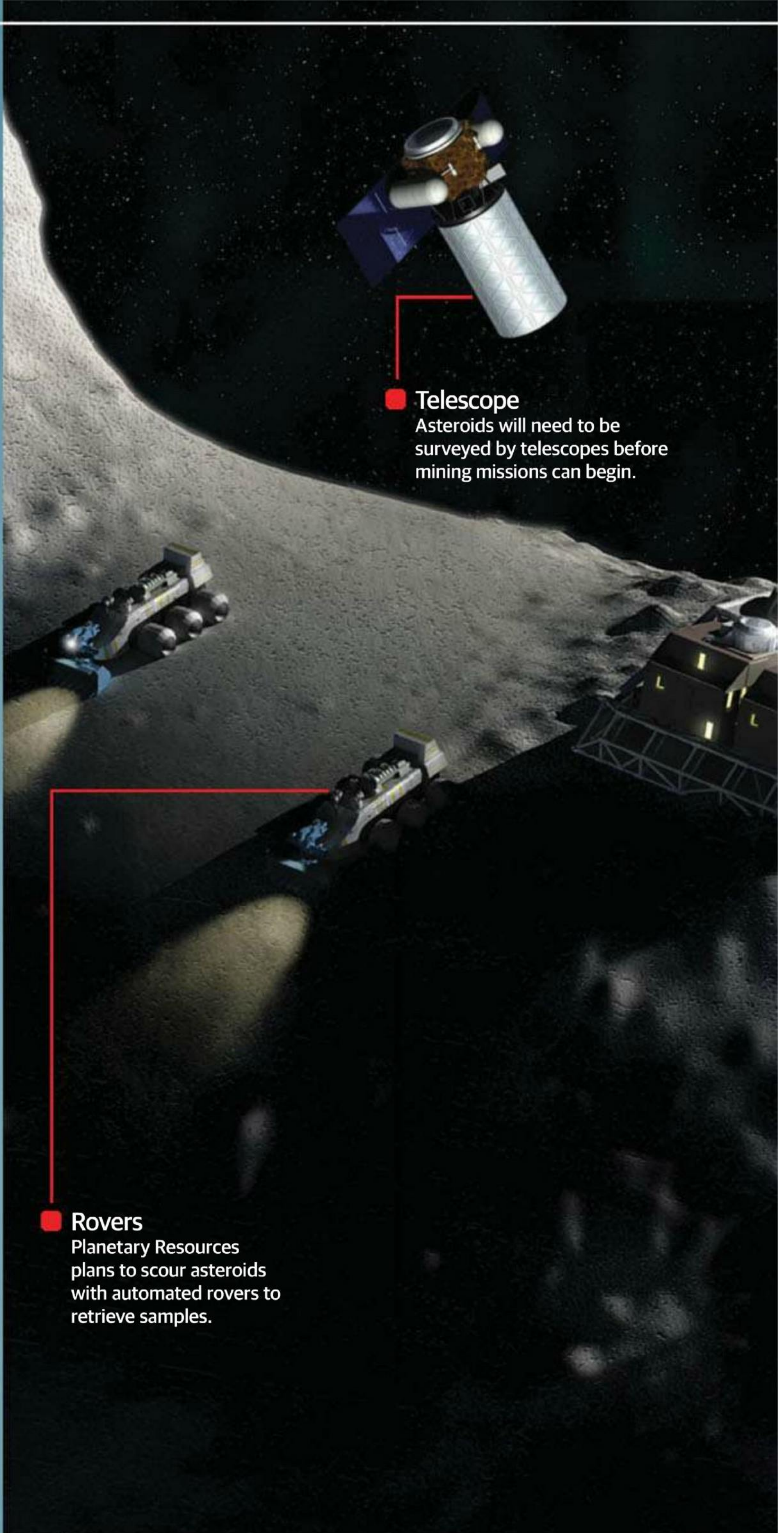
The next step will be to launch similarly sized telescopes with rocket motors. These will venture towards an asteroid and observe it to determine its composition and what resources could be taken from it. Once this has been done the mining can begin.

Well, sort of. Extensive operations won't begin immediately. Instead, they will focus on volatiles such as water, oxygen, nitrogen and others. Gathering up these materials will allow them to be used in refuelling stations. Providing spacecraft with the option of refuelling in orbit could greatly reduce launch costs.

"Accessing a water-rich asteroid will greatly enable the large-scale exploration of the Solar System," said Planetary Resources co-founder Eric Anderson. "In addition to supporting life, water will be separated into oxygen and hydrogen for breathable air and rocket propellant."

The final step will see a team of autonomous rovers scour a chosen asteroid and collect up valuable minerals for an eventual return to Earth. While the exact methodology of how asteroids will be mined is yet to be determined, if a viable plan is formed the returns could be huge.

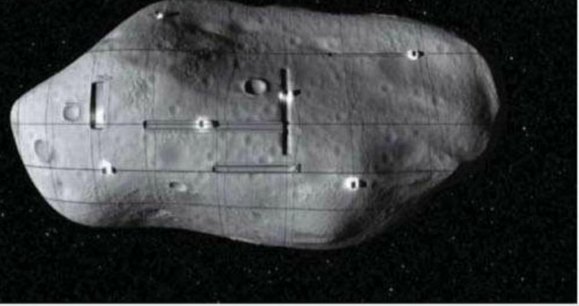
Patience is key, though. Actual asteroid mining by Planetary Resources will likely not begin until the 2020s, and the return of resources to Earth won't start till the 2030s at the earliest. However, the benefits are clear, and if Planetary Resources can maintain its commitment to the project, its goal of giving humans a means to explore the cosmos like never before could yet be realised.

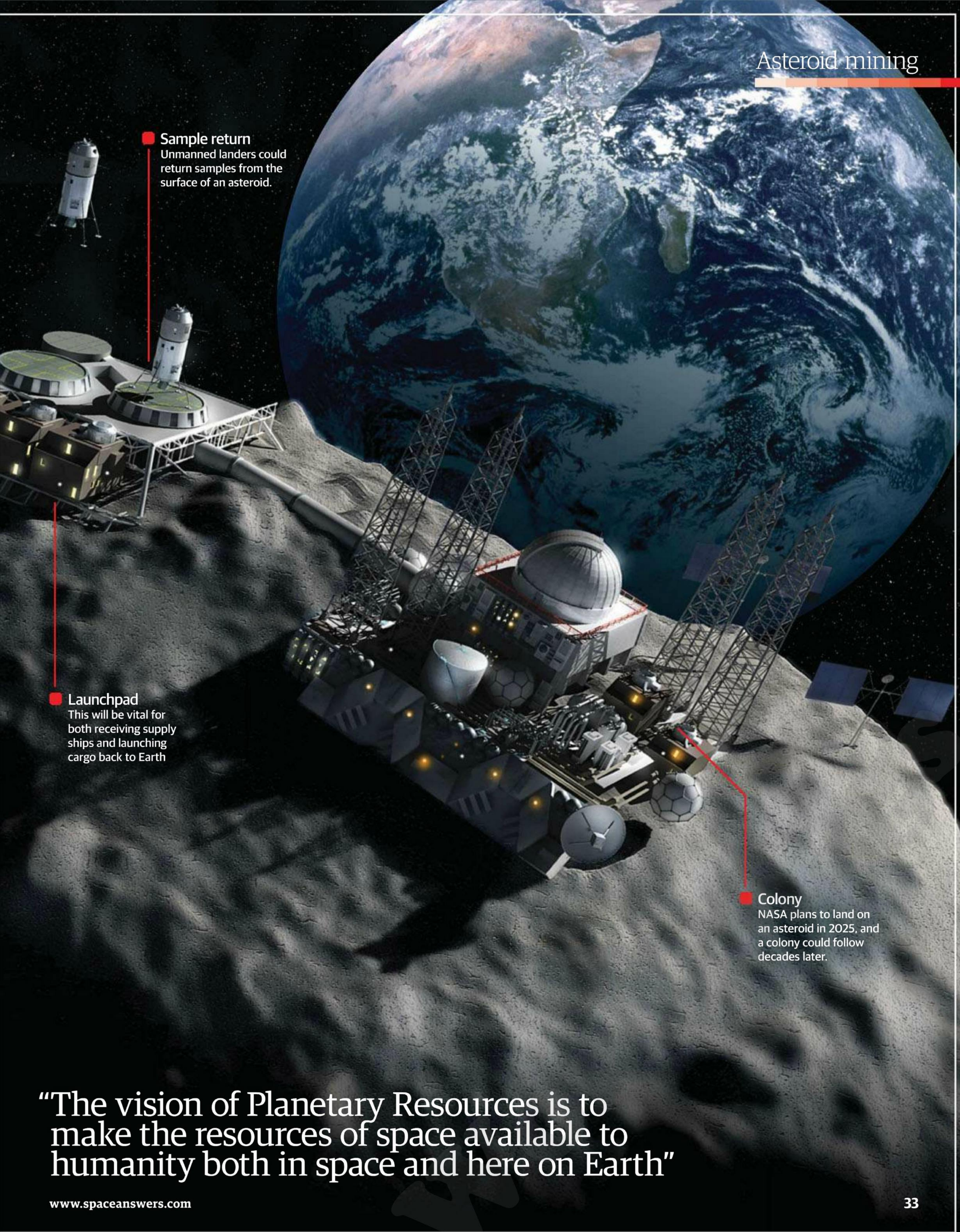


Telescope
Asteroids will need to be surveyed by telescopes before mining missions can begin.

Rovers
Planetary Resources plans to scour asteroids with automated rovers to retrieve samples.

This image from Planetary resources shows rovers scouting an asteroid





Sample return
Unmanned landers could return samples from the surface of an asteroid.

Launchpad
This will be vital for both receiving supply ships and launching cargo back to Earth

Colony
NASA plans to land on an asteroid in 2025, and a colony could follow decades later.

> “The vision of Planetary Resources is to make the resources of space available to humanity both in space and here on Earth”

Andr

omeda

Written by Gemma Lavender

The Andromeda Galaxy is similar to the Milky Way Galaxy in many ways. But what will happen if these two collide in the next 4.5 billion years?

When it comes to next-door neighbours, the Andromeda Galaxy, which rests within the constellation Andromeda, takes the cosmic biscuit. At a hefty 700 billion solar masses and an estimated 220,000 light years in diameter, this galactic giant does not follow its mythological namesake as a princess, but as a queen of the Local Group – a family of galaxies that, almost like Andromeda's minions, lie close by in the trillion star-strong galaxy's queendom. The group also includes the Triangulum Galaxy and our own whirlpool of stars, the Milky Way Galaxy, along with a collection of puny dwarf and irregular galaxies scattered around the more striking trio.

Around 2.5 million light years from the Andromeda Galaxy our own Milky Way, while smaller than the gargantuan queen, almost challenges its galactic ruler, threatening to steal her throne with a contending mass believed to be about 80 per cent of its superior. However, what the Milky Way very nearly matches in weight thanks to the hefty yet elusive dark matter, it loses in presence with a respectable if inferior diameter of 100,000 light years, making it about half the size of its brighter companion and therefore failing to steal the crown of 'size queen'. That said, there's no mistaking that the pair share a similar galactic type with both possessing winding arms that snake their way into space, protruding from luminous cores. Such breed of galaxy is known as the spiral.

While we have never seen our own galaxy from the outside, astronomers believe that its centrepiece is a glowing bulge of stars with a bar cutting through its middle, joining its arms. The origin of the bar is uncertain, perhaps having formed through some gravitational instability, but regardless it is funnelling stars and gas through the galactic centre and out the other end. Structurally Andromeda is not too dissimilar and so, when we look at this galaxy, it is almost as if we are looking at a larger version of how our own Milky Way Galaxy might look were we able to jump into a spaceship and travel hundreds of thousands of light years into intergalactic space to look at it from the outside. A brief glance at the majestic form of a spiral galaxy can easily fool you into thinking that its gigantic structure is just a pattern of swirling stars emanating from a great ball of light at its core. However, there is more to the likes of the Andromeda and Milky Way galaxies than meets the eye and such illusions start at the very heart; what is commonly known as the central bulge of a galaxy.

Through the eyes of visible light, the Andromeda Galaxy is just your typical spiral galaxy with a classic, bulbous central condensation of stars. However, when we look in infrared light, it's a different story as the galaxy's centre takes on a more boxy, angular appearance, leading astronomers to believe that the Andromeda Galaxy is even more similar to the Milky Way than previously thought; a galactic twin with matching barred centres. Perhaps their similarities are not so surprising as studies show that 70 per cent of spiral galaxies have bars.

There's something mysterious about the centre of our Milky Way's grand neighbour. The Hubble Space Telescope peered deep into its heart and found a pair of bright objects at the centre orbiting the dark monster that is a black hole up to 230 million times heftier than our Sun. Again, Andromeda shows our Milky Way to be inferior, with the black hole at the centre of our home only accounting for 4 million times the mass of our star. One of the glowing objects within the centre of Andromeda, which is also known as Messier 31 or M31 for short, is thought by astronomers to be a dense and compact star cluster. The other object is fainter and disc-shaped, spiralling hot gas swirling around the gravitational sinkhole of the black hole. The black hole and the cluster are snugly positioned just five light years from each other. The cluster is dicing with devastation so close to a giant black hole.

Out from the centre the bar links two spiral arms that wrap around Andromeda in a tight embrace. In the spiral arms is gas and dust and stars, with nebulae formed of the former two making the latter. Here too Andromeda triumphs over the Milky Way – deep images of the galaxy reveal a hidden outer layer that expands the spiral arms to around 220,000 light years, about twice the diameter of our galaxy.

Around the spiral arms and the centre is the stellar halo and while the spiral arms may be fresh-faced youngsters relatively speaking, the halo is positively ancient, home to the oldest of Andromeda's hundreds of billions of stars. The visible stellar halo also merges with the invisible dark matter halo that surrounds and encases the entire Andromeda Galaxy and holds it all together. Inside the halo there are also globular clusters, numbering around 460 in total and the biggest of them is called Mayall II, or alternatively G1, but this cluster of many guises is vastly greater in size and number of stars than any globular cluster around the Milky Way. It seems as though everything about Andromeda is bigger – a true giant.

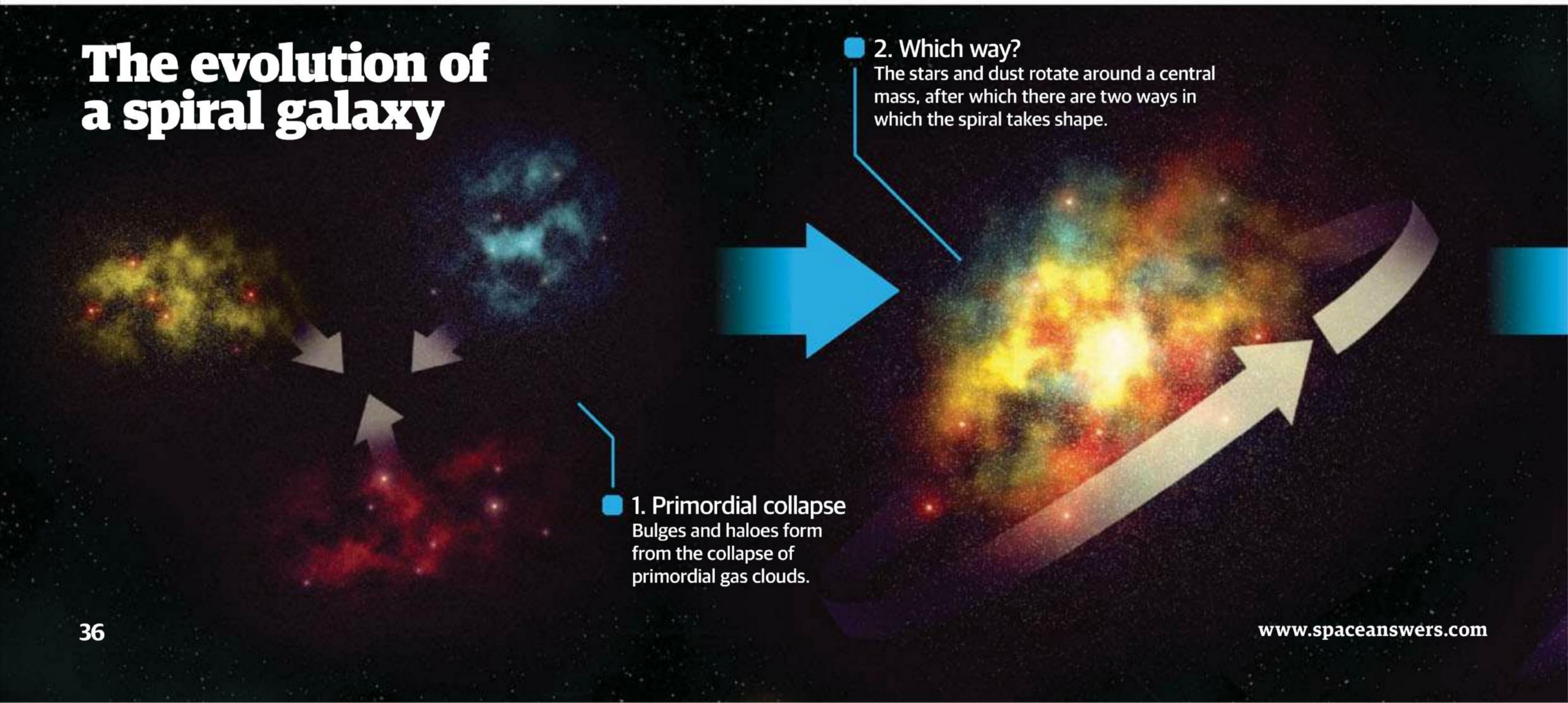
Flanking Andromeda are around 14 dwarf galaxies which stick close to the structure. Perhaps the most famous of the group are the dwarf elliptical galaxies known as M32, also nicknamed Le Gentil, and M110. Messier 32 may have once been a larger galaxy – there is evidence that it is interacting with its bigger neighbour which is using its gravity to pluck the stars and gas from M32 and shrinking it. The evidence for this is that it has its own supermassive black hole about a million times greater in mass than our Sun, and only big galaxies get black holes so massive. Our Milky Way has its own satellite galaxies, including the Magellanic Clouds, but neither of them have black holes as big as M32. Andromeda wins again.

Watching Andromeda strut its stuff in visible light can only tell us so much about our nearest big neighbour but high above Earth are robotic eyes that have X-ray, ultraviolet and infrared vision. The Hubble Space Telescope isn't alone in space, with other space observatories covering the other parts of the electromagnetic spectrum of light. These include the Spitzer Space Telescope, which can see infrared light from cool things like clouds of gas that are turning into stars, or faint stars that only shine with a feeble glow. Meanwhile there is also the Galaxy Evolution Explorer that can see ultraviolet light from hot things such as bright, young stars – if a region of a galaxy is shining bright in ultraviolet light, then it is very young, forming lots of new stars. On the other hand, if it is dim in ultraviolet and bright at infrared wavelengths, it implies that the region of the galaxy is far older, with only the cooler, long-lived stars around. Together they have stared at Andromeda, showing the galaxy in a new light. At the wavelengths of ultraviolet and infrared, sunglasses aren't needed to cut down on the glare of the galaxy that we see in normal light. GALEX and Spitzer look right through, revealing the spiral disc to be harbouring several rings expanding away from the centre, possibly caused by M32 passing through the Andromeda Galaxy, causing ring-like ripples similar to waves in a pond where a stone has been dropped in. Some galaxies in the universe are ring shaped, with a starry circle of gas and dust lopping around and separated from a bright centre. Andromeda may be on the way to growing into a ring-shaped galaxy.

Across the vast reaches of the universe, galaxies are steadily rushing away from our own as the

> "The Hubble Space Telescope found a pair of objects at the centre orbiting the monster that is a black hole up to 230 million times heftier than our Sun"

The evolution of a spiral galaxy

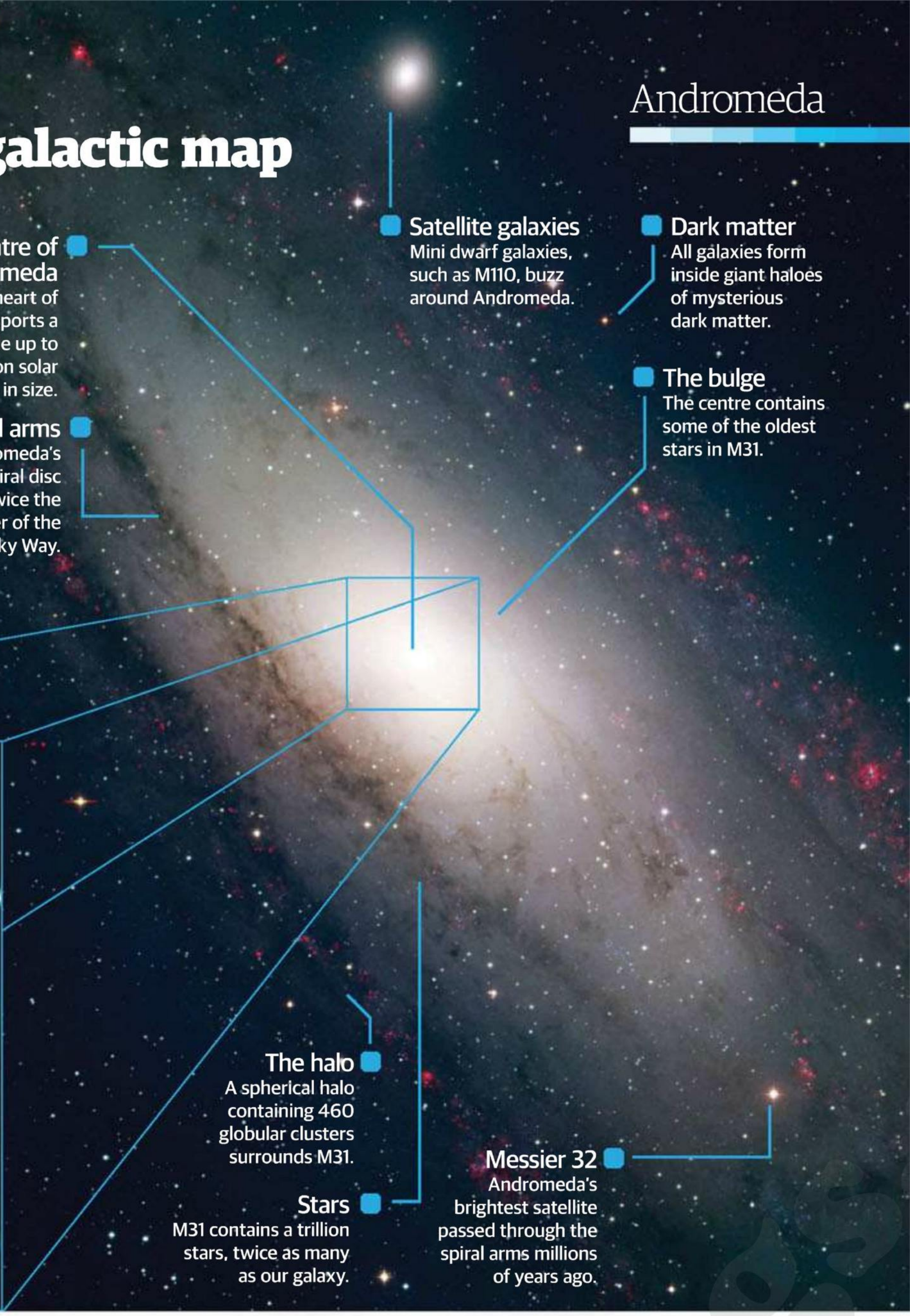


2. Which way?
The stars and dust rotate around a central mass, after which there are two ways in which the spiral takes shape.

1. Primordial collapse
Bulges and haloes form from the collapse of primordial gas clouds.

A galactic map

GALEX being mated to its Pegasus XL Rocket on 7 April 2003



Centre of Andromeda
The heart of M31 sports a black hole up to 230 million solar masses in size.

Spiral arms
Andromeda's spiral disc is twice the diameter of the Milky Way.

Satellite galaxies
Mini dwarf galaxies, such as M110, buzz around Andromeda.

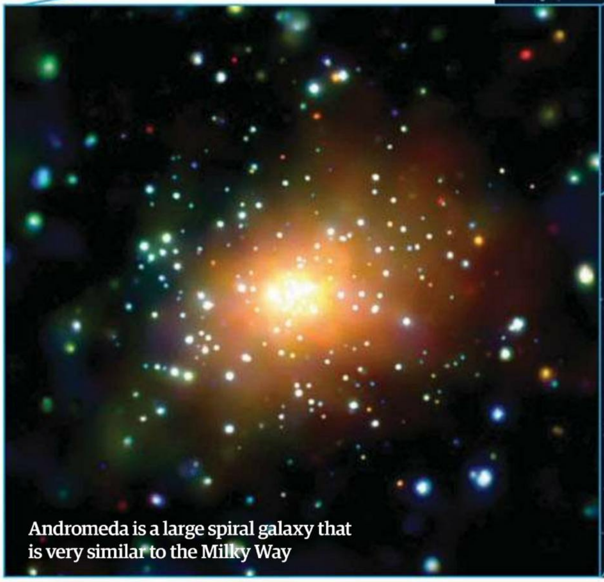
Dark matter
All galaxies form inside giant haloes of mysterious dark matter.

The bulge
The centre contains some of the oldest stars in M31.

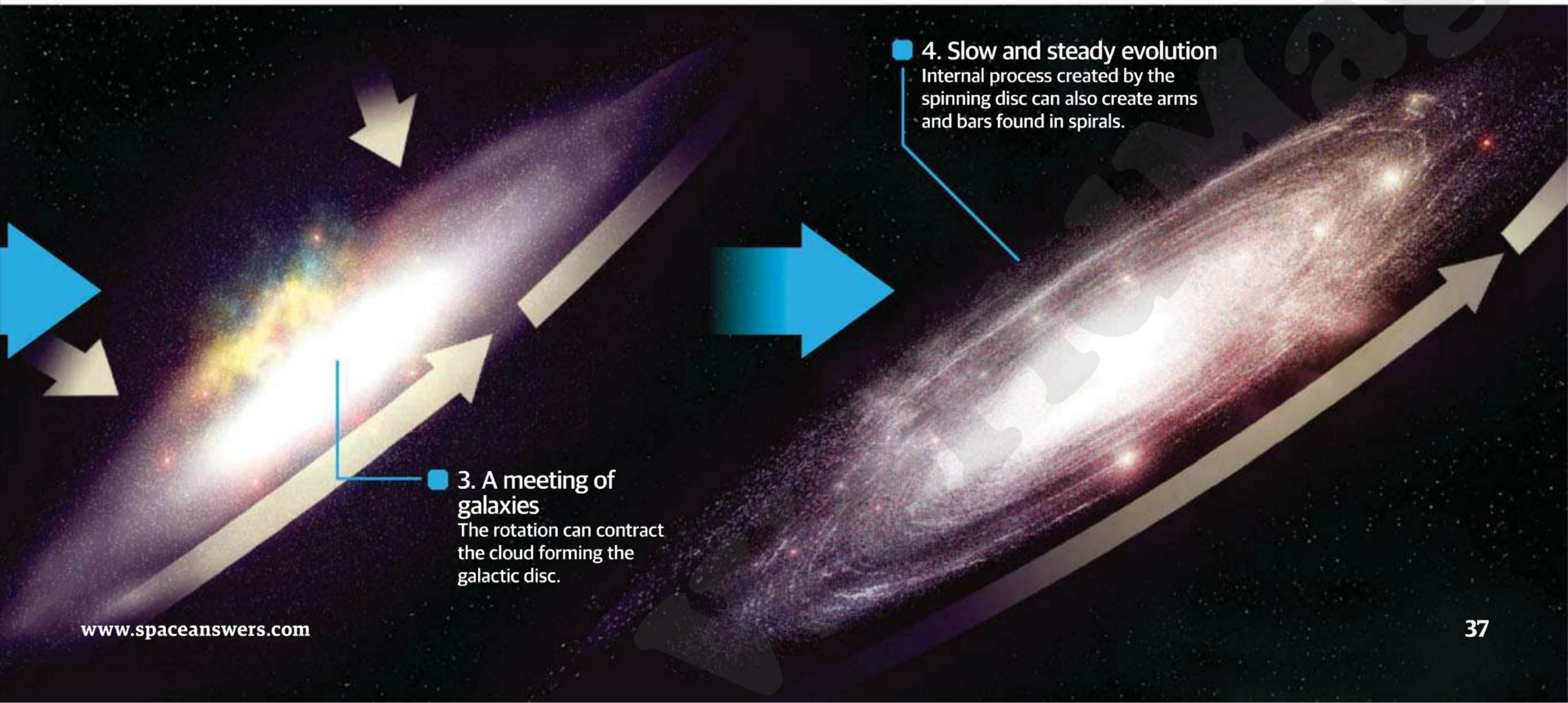
The halo
A spherical halo containing 460 globular clusters surrounds M31.

Stars
M31 contains a trillion stars, twice as many as our galaxy.

Messier 32
Andromeda's brightest satellite passed through the spiral arms millions of years ago.



Andromeda is a large spiral galaxy that is very similar to the Milky Way



4. Slow and steady evolution
Internal process created by the spinning disc can also create arms and bars found in spirals.

3. A meeting of galaxies
The rotation can contract the cloud forming the galactic disc.

Anatomy of Andromeda

Tell-tale dust ring

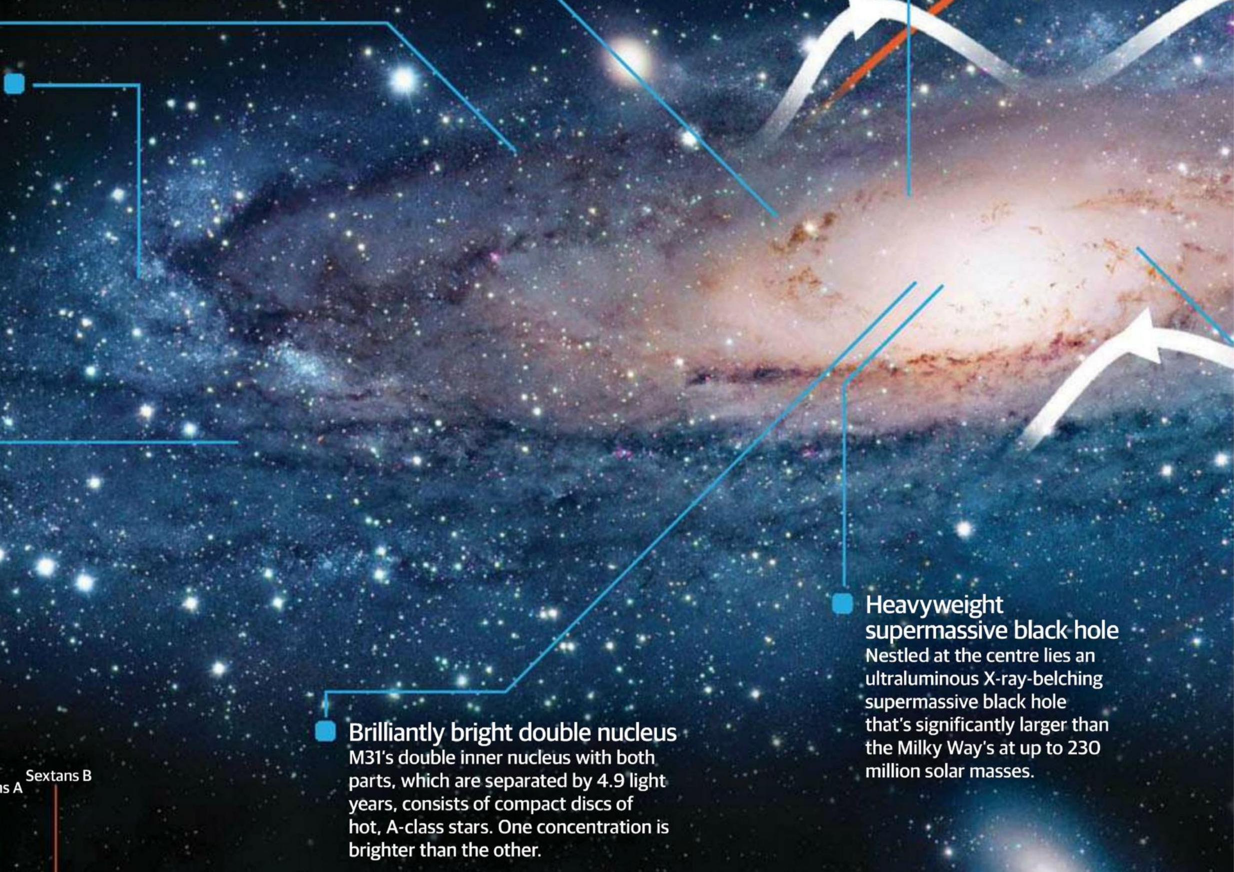
Close examination of Andromeda in the infrared reveals a dusty inner ring believed to have been caused by satellite galaxy M32 ripping straight through its disc more than 200 million years ago.

S-shaped disc

Inclined at roughly 77 degrees relative to the Earth, Andromeda has a strange warped disc in the shape of an 'S', possibly caused by the gravitational interaction of satellite galaxies.

A 'misleading' bulge

In visible light, you wouldn't think that a bar streaks through Andromeda's centre. That is until you look at this section of the galaxy in the infrared.



Winding arms

Wound up in a clockwise direction, M31's spiral arms are outlined by low-density clouds of partially ionised gas where the formation of young hot blue stars have recently formed.

Dust and gas

Cold dust and gas is arranged into overlapping rings according to an infrared to ultraviolet view, causing astronomers to believe that Andromeda may be transforming into a ring galaxy!

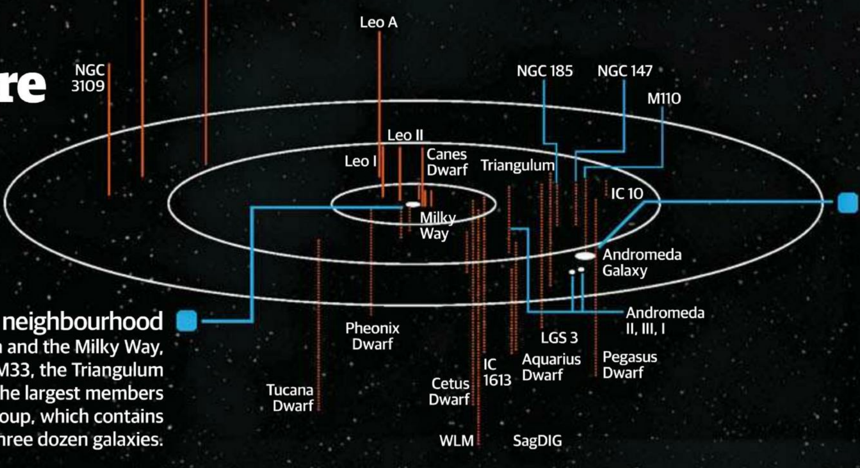
Brilliantly bright double nucleus

M31's double inner nucleus with both parts, which are separated by 4.9 light years, consists of compact discs of hot, A-class stars. One concentration is brighter than the other.

Heavyweight supermassive black hole

Nestled at the centre lies an ultraluminous X-ray-belching supermassive black hole that's significantly larger than the Milky Way's at up to 230 million solar masses.

Where is it?



Our neighbourhood

Andromeda and the Milky Way, along with M33, the Triangulum Galaxy, are the largest members of the Local Group, which contains around three dozen galaxies.

Collision course

Andromeda and the Milky Way are speeding towards each other at 400,000km/h. There's also evidence that Andromeda and the Triangulum Galaxy interacted in the past.

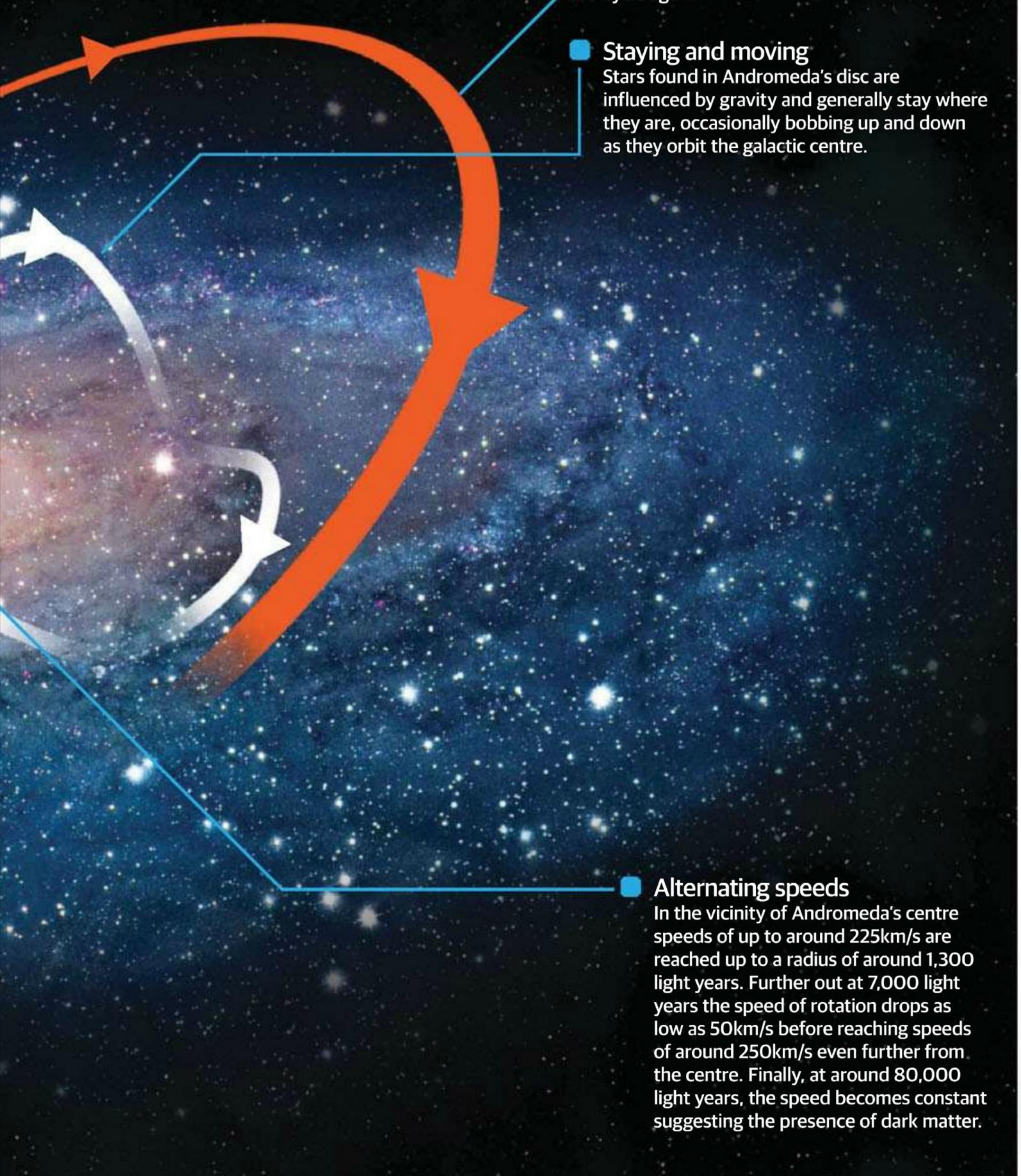
Dwarf galaxies

Andromeda is accompanied by around 14 known dwarf galaxies, the most famous being M110 and M32, along with around 460 globular clusters. Faint galaxies around Andromeda could help astronomers learn more about dark matter.

Galactic star paths

'Jumping' stars and clusters
Stars found in the galaxy's halo (and globular clusters) may 'jump' high above the disc before diving back in again popping out of the bottom of the galaxy before starting the cycle again.

Staying and moving
Stars found in Andromeda's disc are influenced by gravity and generally stay where they are, occasionally bobbing up and down as they orbit the galactic centre.



Alternating speeds
In the vicinity of Andromeda's centre speeds of up to around 225km/s are reached up to a radius of around 1,300 light years. Further out at 7,000 light years the speed of rotation drops as low as 50km/s before reaching speeds of around 250km/s even further from the centre. Finally, at around 80,000 light years, the speed becomes constant suggesting the presence of dark matter.

From the side

Globular clusters
The stellar halo is home to groups of stars called globular clusters. The largest around M31 is called Mayall II. It's twice as big as the Milky Way's largest.

Bulging out
The reason for the bulge's name is clear when the galaxy is viewed from the side. It hides a huge black hole, much heavier than the Milky Way's.

Thick and thin
The discs are divided into 'thick' and 'thin'. The thick disc contains stars over 8 billion years old, while a thinner disc houses younger stars.

Gas and dust
The spiral disc is filled with gas and dust. Dust is produced by dying stars and recycled into new stars born in nebulous regions of gas.

cosmos expands. It seems, however, that the Andromeda Galaxy has other ideas as it moves like a juggernaut in the opposite direction, charging at the Milky Way in what seems like slow motion – at a speed of around 400 light years every million years, Andromeda is set on a path of destruction that could see our galaxy getting walloped by it in the next four and a half billion years.

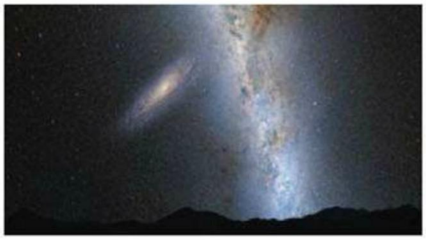
Crashes and cannibalism between galaxies isn't uncommon in the universe. Both the Milky Way and Andromeda Galaxy have form when it comes to gobbling up small galaxies and smashing into others. The former – our galaxy – is currently gaining more mass by snapping up several dwarf galaxies and cannibalising them – its next meal is likely to be our small elliptical companion the Sagittarius Dwarf Elliptical Galaxy (SagDEG), which has been drawn out into a loop around the Milky Way some 10,000 light years across by our galaxy's gravity. The loop is made up of spherical collections of stars also known as globular clusters, which are set to slowly merge with the larger Milky Way Galaxy. Meanwhile, evidence abounds in the form of tattered remnants of dwarf galaxies that shows the Andromeda Galaxy also has a track record of indulging in the odd galaxy or two.

While being in the path of a galaxy twice the size of our own would spell disaster in the minds of many, astronomers have been left wondering if the collision between our two giant stellar conurbations could happen at all. If the ultimate crash does come to pass, stars in both parties would largely miss each other as the space between stars is so enormous that the likelihood of any colliding is mind-bogglingly tiny. However, the gravitational fields of both galaxies will play havoc with the stars and gas clouds in both galaxies, throwing them around like toys. Just what will happen to our Solar System by the time 4.5

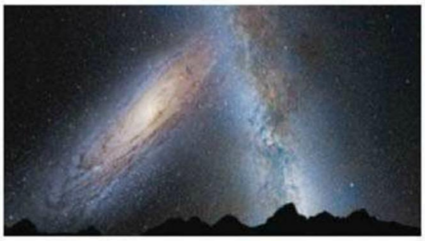
Spitzer after cryogenic telescope assembly integration

When galaxies collide

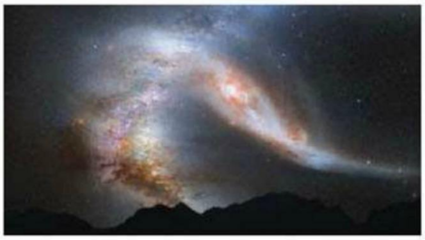
Although Andromeda is currently over two and a half million years from our own galaxy, in the next several billion years it will collide with the Milky Way. For any humans who are still around then, the sight is set to be remarkable. Our neighbouring galaxy will gradually grow larger and larger in the night sky before the two collide in a collage of exploding stars, twisting spirals and merging black holes.



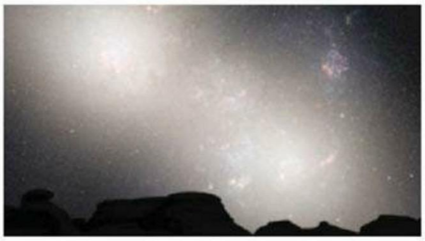
2 billion years
The disc of the approaching Andromeda Galaxy will be noticeably larger.



3.75 billion years
Andromeda will fill the field of view and begin pulling the Milky Way.



4 billion years
Andromeda will be tidally stretched and the Milky Way will become warped.



5.1 billion years
The cores of the Milky Way and Andromeda will appear as a pair of bright lobes.

billion years rolls around almost seems irrelevant and will not affect us in the slightest for one main reason; our planet as we know it will by then have a swelteringly hot surface so high in temperature that water will boil away, ending all life upon it. The massive change from tranquility to hell on Earth will not be down to a sudden alteration on our planet's part, but will be down to the ageing of our Sun with it becoming brighter and therefore hotter a good 1.4 billion years from now, long before the end of its life.

The great event between the two galaxies might be a show that human beings are very unlikely to see, but that has not stopped astronomers from modelling just what will happen to our Solar System when the two do finally meet. They found that if Andromeda and the Milky Way do unite in the form of a merger, there is a possibility that our Solar System will be thrown out a good three times further away from its current position in the crook of the Orion arm, which rests around 28,000 light years from the centre of our galaxy. Another possibility, albeit a small one, is that our Solar System will be discarded and thrown out completely by the pair just as they collide to form a giant elliptical galaxy that astronomers have already nicknamed 'Milkomeda'.

That is not all. The mammoth collision between the gigantic duo could create a quasar at the centre of the newly formed Milkomeda. As the galaxies merge, so do the black holes, as the forces of the merger assist in pushing gas down the mouth of the giant black hole, and the gas heats up before it reaches the black hole, glowing brightly as it is sent to its doom. Such active black holes are called quasars, which are so bright they can be seen across the universe. Meanwhile the gas-laden cores of the galaxies will erupt with star formation – a final generation of new stars before all the gas is used up and the quasar runs out of gaseous food to chomp on. Then Milkomeda will become a quiet, ancient galaxy that will grow old respectably.

1. Clean room
White-suited workers at the Kennedy Space Center in Florida inspect the Spitzer spacecraft after its trip back to the clean room in May 2003.

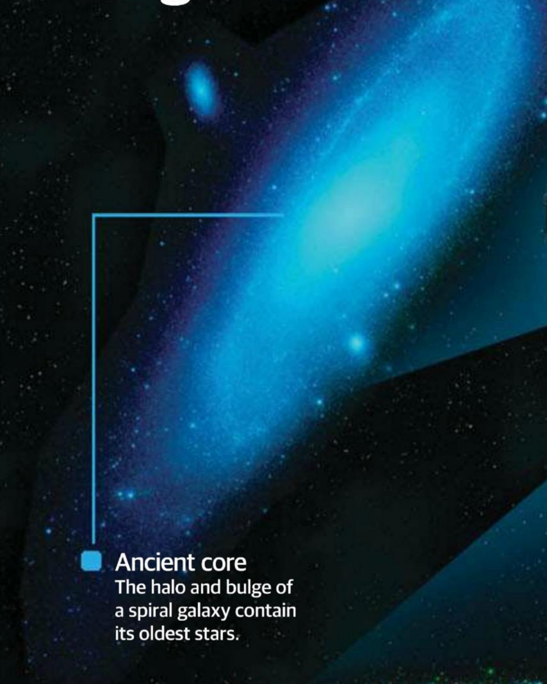
2. Ready for launch
Spitzer is moved into position to have its launch faring installed atop its Delta rocket on 10 April 2003, ready for its launch later that year.

3. GALEX covered
Workers check the deployment of the cover of the telescope on the GALEX satellite.

4. CTA testing
The Spitzer cryogenic telescope assembly (CTA) being prepared for vibration testing.

5. GALEX launch
Being attached to a Lockheed L-1011 TriStar in preparation for launch.

Viewing our galactic neighbour



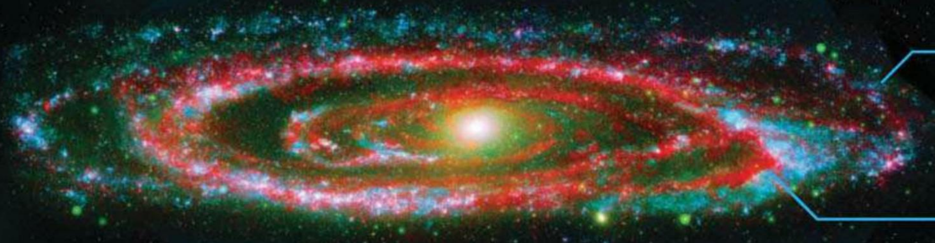
An old face
This Spitzer image shows Andromeda's older population of stars.

Ancient core
The halo and bulge of a spiral galaxy contain its oldest stars.

Mission Profile

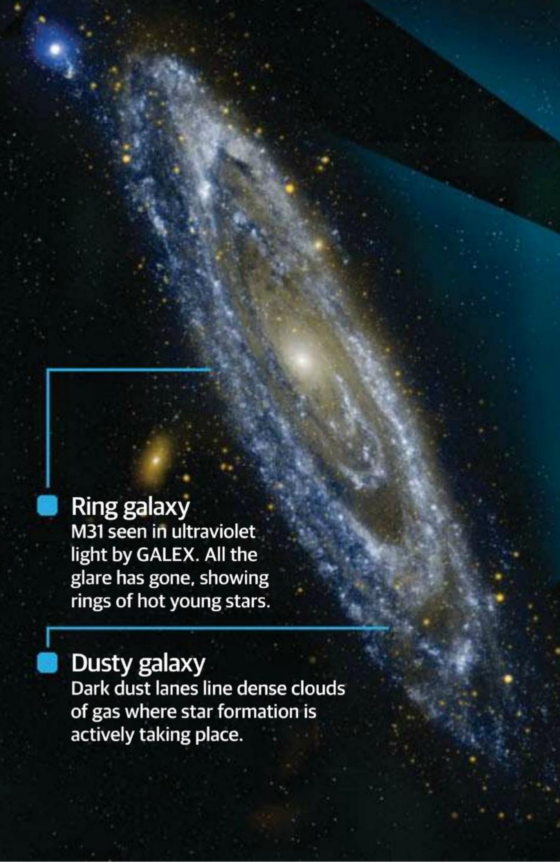
Spitzer Space Telescope

Launch date: 2003
Launch vehicle: Delta II rocket
Mass: 950kg (2,100lb)
Telescope diameter: 0.85m (33in)
Mission: NASA's Spitzer Space Telescope observes the universe in infrared wavelengths, which can penetrate through interstellar dust.
Key discoveries: Spitzer probes the interiors of star and planet-forming regions, as well as the structures of galaxies, determining the interstellar chemistry of those regions. It has also probed the atmospheres of exoplanets.



Old and young
This false-colour composite of images reveals the ring structure of M31's disc, and the populations of old and young stars.

Hot and cold
The hottest stars (blue) are also the most massive and youngest, whereas older stars (green) are less massive and cooler.



Ring galaxy
M31 seen in ultraviolet light by GALEX. All the glare has gone, showing rings of hot young stars.

Dusty galaxy
Dark dust lanes line dense clouds of gas where star formation is actively taking place.

Mission Profile

Galaxy Evolution Explorer (GALEX)

Launch date: 2003
Launch vehicle: Pegasus rocket
Mass: 280kg (620lb)
Telescope diameter: 0.5m (19.7in)
Mission: This NASA ultraviolet space telescope is designed to study the structure and evolution of galaxies by observing its stars.
Key discoveries: GALEX has watched active black holes, captured images of galaxies plunging through other galaxies and spotted starbirth in the outer realms of galaxies.

“I implored my parents to let me stay up and watch The Sky At Night. I was glued to it”

Brian May
Why space rocks

Written by Jonathan O'Callaghan

The legendary Dr Brian May of Queen fame tells us how he got involved with astronomy, and why he's still so passionate about the cosmos today

May fell in love with astronomy after watching Sir Patrick Moore on *The Sky At Night*, a show he occasionally appears on alongside Moore and Chris Lintott

Until a few years ago the name Brian May was not one that evoked thoughts of an astronomer gazing at the night sky. After Queen launched into superstardom status, with May as lead guitarist, the world of telescopes was put on the back burner as hit after hit topped the charts. Unbeknown to many, however, was May's love of astronomy that began even before he became one of the most famous guitarists in the world.

Sitting down with May at the launch of his new book, *The Cosmic Tourist*, co-authored with *The Sky At Night* presenters Sir Patrick Moore and Dr Chris Lintott, May revealed what first got him interested in astrophysics and astronomy: "The answer is Patrick, completely Patrick. Single-handedly he inspired a whole generation, actually quite a few generations, that they can look up and outwards and start to wonder about the sky at night. That was me, I was entranced from about the age of eight or nine, and it never left me."

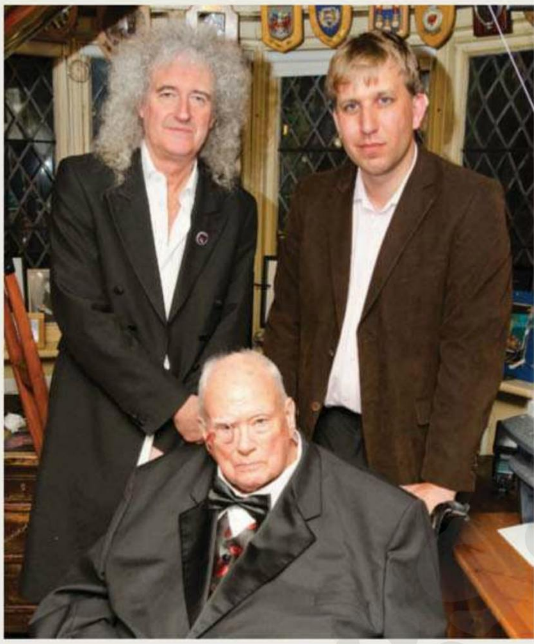
May's admiration of Sir Patrick was apparent from the word go: "I got one of [Sir Patrick's] books from the school library and read it from cover to cover many times, and I discovered I could actually see the man on TV. So I implored my parents to let me stay up and watch *The Sky At Night* and I was glued, absolutely glued to it, and have been ever since."

While Sir Patrick has been a major influence in May's life, he cites others as being a further cause of his early love for astronomy even before his Queen days, and indeed it was that motivation that led him into a degree in physics and maths at Imperial College, London, in the late Sixties: "The reason I did my physics degree at Imperial College was because I had astronomy in mind," said May. It was a radio astronomer by the name of John Shakeshaft that provided further inspiration for May after giving a lecture at his school, where "I collared him and said I wanted to be an astronomer, asked him how I'd do it, and he said to do physics at university."

After passing his Bachelor's degree, May progressed on to "doing a postgraduate course for a PhD and a project in the infrared astronomy department, although what I did was actually optical Doppler shift astronomy. What I was doing was looking at dust in the Solar System and the dynamics of it." It wasn't all plain sailing, however. "Somewhere along the line I got a little distracted with music!" joked May. Thirty years is quite a distraction, but understandably May said he "wasn't sad" at dropping his PhD to join Queen.

On whether he maintained his interest in astronomy during his Queen days, May told us that "yes, I really did" but it was his thesis that provided the incentive to leave the PhD behind. "To be honest I came to a very sticky point in my thesis. I'd done three years of study and I'd written most of it up, and I'd also done an extra year supporting myself by teaching maths in a comprehensive school. So I did four years on the whole, I'd written it all up, done all the pictures and diagrams and index. Then my supervisor said it was really good but why don't I go back and do a little bit more here and there. To cut a long story short I just said I couldn't do it. I never got as far as submitting it to the authorities."

From there, May "put it to one side, thinking maybe one day" he'd return to it, but it wasn't until 30 years later that he unearthed his thesis "in about three different trunks in my loft" and came back to it. "It was Patrick again," May said. "I came to know Patrick not through astronomy but through a radio programme, and in this radio programme I did some music for it and became very good friends with Patrick. From time to time he'd ask me what happened to my PhD, and why don't I go and finish it off. I said to Patrick how could I possibly do that now,



The life of Brian

19 July 1947
Birth
Brian Harold May was born in London, England.

1970
Starts PhD
Undertakes a PhD in astrophysics at Imperial College London.

1971
Joins Queen
Leaves university to join supergroup Queen full-time.

13 July 1985
Live Aid
Queen perform at Live Aid, with arguably one of their greatest shows.

2005
Receives CBE
Awarded CBE for services to music and charity work.

1 October 2006
Completes PhD
Re-registers for previously unfinished PhD, and completes it on 2 August 2007.

The Orion Nebula. May says that looking at the night sky has helped him through some tough times

May has no regrets about dropping out of university to join Queen, but was pleased to finally complete his PhD in 2007

> "It's the most spiritually empowering thing that I know, to look up at the night sky and see Orion rising as the autumn closes in"

it's got too far away! And he said, 'no it hasn't, you could do it, why don't you do it?'"

While May started to consider going back to finish what he'd started 30 years ago, he needed one last push to be tempted back into the world of academia after spending so long living as a rock star. "I started talking about it in the press because people started asking me for some reason," said May. "One of the articles was read by the head of astrophysics at the Imperial College at the time, Professor Rowan-Robinson, and he wrote me an email that was probably one of the biggest shocks of my life! It said, 'I've read the article [in the media], if you are serious about finishing off your PhD in astronomy I will be your supervisor. Come back to Imperial College and we will finish off your PhD.'"

It was a difficult decision for May, but in the end he said "it was an offer I couldn't refuse. But I had to throw up my life. I just ditched everything for a year, and I pretty much gave up three times because it was so difficult to pick up the threads [of my old thesis]."

We sensed, however, that despite all the hardship May was glad to go back and finish what he had started. "It was thrilling when I finally got that thing done," May admitted. "I cannot tell you what that feels like when you've been through all that stuff. The examiners were [bad] though, they were so hard on me, I don't know if they wanted to make an example of me! I had a real tough time with my external examiners but when I eventually did the corrections and took it back and they said okay, you can have your PhD, I was so thrilled because it was like fulfilling a circle that I'd always wanted to do."

It's safe to say that May's time with astronomy hasn't been a straightforward one, but he told us he still practises astronomy and appears on *The Sky At Night* "occasionally" despite being "a bit busy". And he still retains the same passion for astronomy that he's always had: "Oh absolutely, yeah. It's to me endlessly stimulating and challenging, I love it."

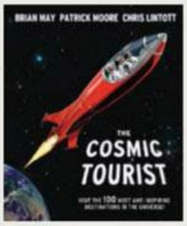
For all his experiences, and especially considering his PhD, we asked May what he thought the best way for someone new to space and astronomy was to get involved with the field. "Well, I'm sure if they're reading your magazine they'll already be involved," he said. Magazines and books are a great starting point, according to May, but for him it's the wonder of looking at the night sky that really instils the greatest feeling. "Find yourself a dark place, go outside, give your eyes about 20 minutes to become accustomed, which most people don't realise, and look up at the night sky and start there. Learn your way around the constellations because it's magic, you'll learn your way around a land, a territory, which will be with you all your life, and you will see these seasons change time after time and your old friends will come back every year.

"It's the most spiritually empowering thing that I know," May continued, "to look up at the night sky and see Orion rising as the autumn closes in at the last moment, and it's got me through some very hard times. When I had a couple of serious bouts of depression in my life the stars were a big factor in pulling me out. People used to say 'what's your spirituality?' and I'd say I don't know, but I found out looking at the stars one night that that's what it was."

Having rekindled his love for astronomy, May is now actively involved in the field. As well as appearing on *The Sky At Night* from time to time he collaborates with Sir Patrick and Chris Lintott, including on their latest book, *The Cosmic Tourist*. May's Queen days may be over, but we can be sure his return to astronomy is only just beginning. ●

We spoke to May at the launch of his new book, *The Cosmic Tourist*, co-authored with Lintott and Moore

The Cosmic Tourist



The Cosmic Tourist (£25) by Brian May, Patrick Moore and Chris Lintott is a wonderful tour of the cosmos from Earth to the edge of the universe with three of the world's best-known astronomers. It's published by Carlton Books and available to buy online and from all good book shops.

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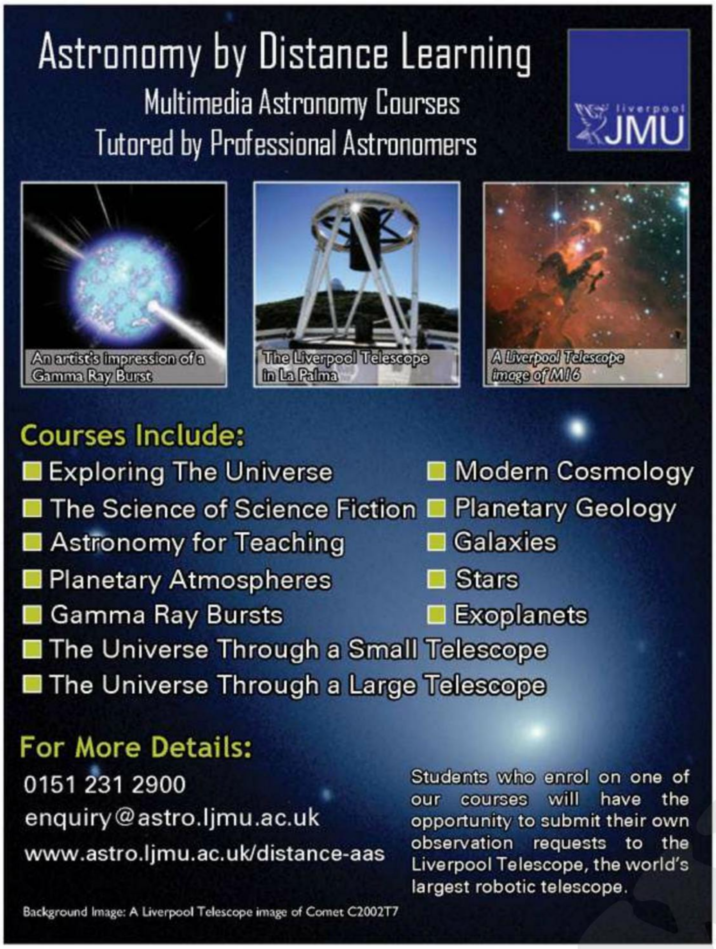

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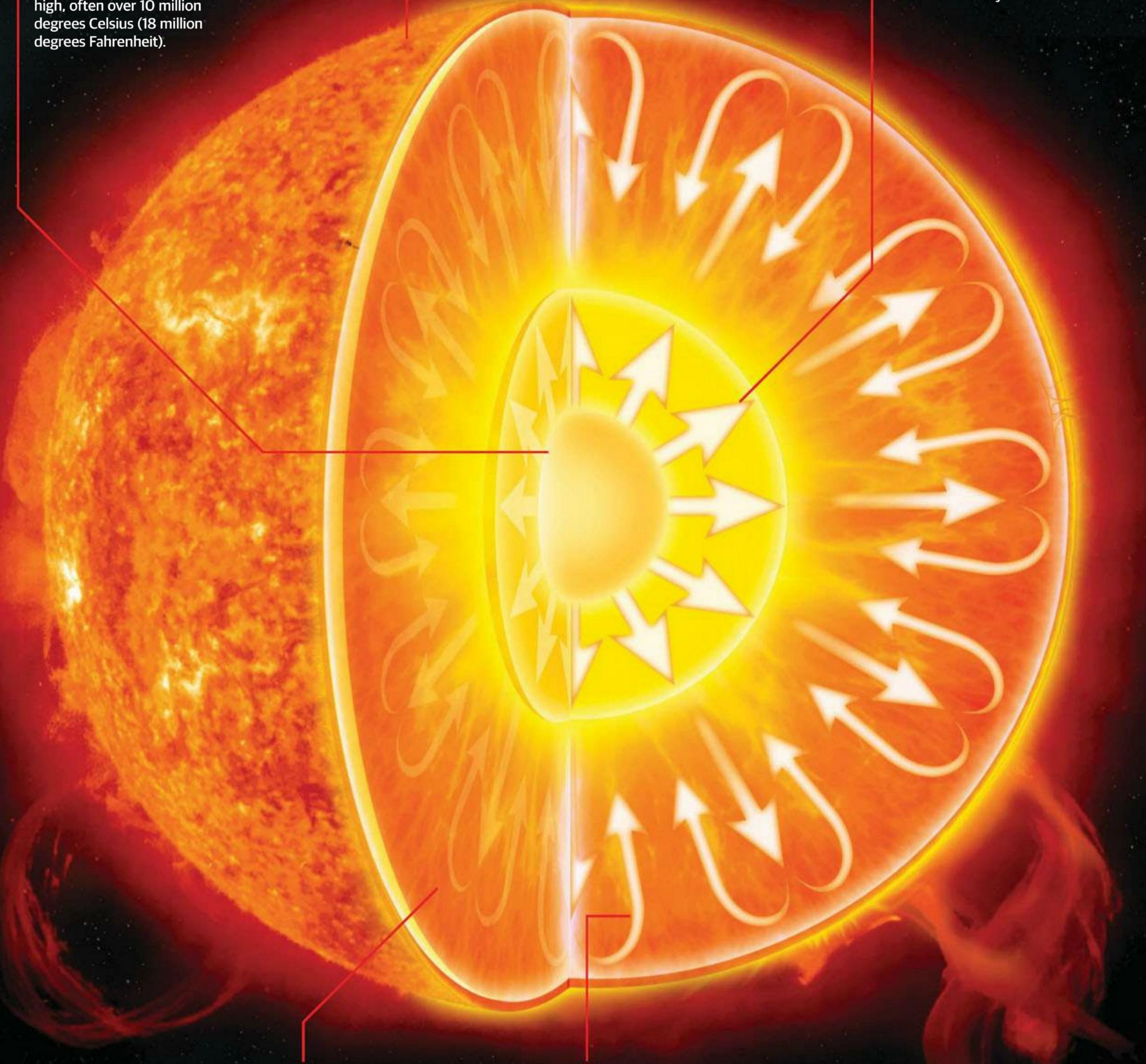
Anatomy of a star



Core
The core of stars is where the vast majority of their nuclear fusion reactions take place. Temperatures are incredibly high, often over 10 million degrees Celsius (18 million degrees Fahrenheit).

Magnetic field
Magnetic fields permeate all stars, with magnetic field lines arranged according to local conditions. Earth's Sun has a dipole magnetic field. These fields are commonly distorted by the star's internal dynamo.

Radiative zone
Each star has a radiative zone where energy from the core is directly radiated outwards through its gaseous material. Low-mass stars have radiative inner layers, while high-mass stars have radiative outer layers.

Subsurface flows
Subsurface flows are driven by both the distorting effect of the star's dynamo and also, on low-mass stars, by large convection zones that unstably transfer energy to the near surface in circular motions.

Convection zone
Driven by the fluid motion within the star's shells, convection zones are the secondary energy transportation process within stars. They only occur when radiative heat transfer is ineffectual, due to a high opacity of shell material.

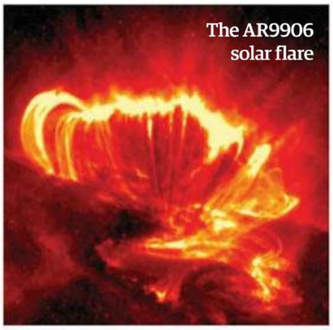
What happens inside a star?

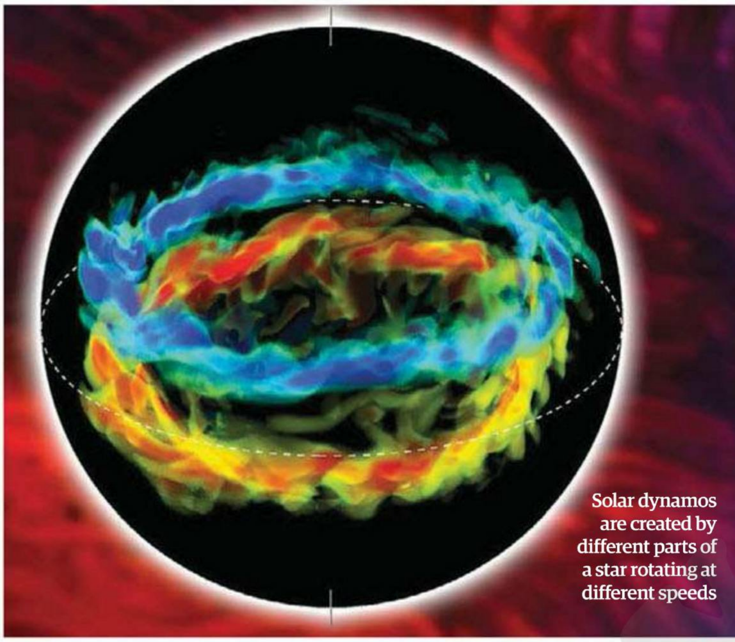
While the surface of a star – known as its photosphere – appears a busy place, it is nothing compared to its interior, which is a hive of physical processes

First, there is the process of hydrostatic equilibrium, which largely determines the star's density structure and is a counteracting sequence where the star's internal pressure gradient pushes against and counteracts the force of gravity. In essence, this determines the stability of the star's shell structure, its various rings of material (such as plasma) and forces emanating from the core. Without this stability, the various shells of the star will either contract or expand. For a star like our Solar System's Sun, the hydrostatic balance is finely tuned, as the star has been stable for over 7 billion years. However, for a star such as red supergiant Betelgeuse, it is not, hence the uneven shell structure.

The second key physical process within stars is energy transportation, which is important as the temperature of its gas determines the density structure via its hydrostatic equilibrium. The transportation of energy within stars can happen via two processes, either by radiation or convection. In main sequence stars – such as our Sun – these processes are typically localised in radius to specific zones, with their position determined by the star's mass and shell opacity. Stars with masses over seven times that of the Sun are convective in their inner layers, while radiative in their outer ones due to their high internal mass. In contrast, stars with low mass, tend to be radiative in their inner layers but convective in the outer layers as their opacity is lessened due to their lower internal mass.

Finally, the third key process within stars is nuclear fusion, a series of reactions which occur primarily in the star's core (see the 'Fusion power explained' boxout for more information). These fusion reactions necessitate high temperatures in excess of 10 million degrees Celsius (18 million degrees Fahrenheit) and high densities greater than hundreds of grams per cubic centimetre. Interestingly, the more massive a star is the shorter its life span becomes, as the nuclear fusion in its core occurs at a far quicker rate despite the increased quantity of fusionable material. As such, stars of similar size to our Sun will have a main sequence of approximately 10 billion years, while a star ten times as massive would only last around 20 million years. ■


The AR9906 solar flare


Solar dynamos are created by different parts of a star rotating at different speeds

Stellar dynamos

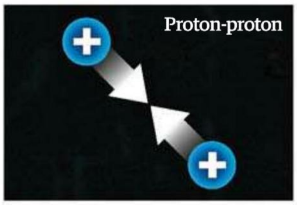
Many stars have a solar dynamo – vast rings of electrically conductive plasma that are charged through a shearing effect between different parts of the star rotating at different speeds. This shear charges the plasma to such an extent that they can warp the magnetic field lines.

This distortion is so severe that the magnetic field lines tend to be dragged along with the fluid in a whipping motion. Indeed, it is because of this distorting effect that many stars demonstrate sunspot cycles, with the star's dynamo extending its field lines so much that they pierce the surface of the photosphere.

Fusion power explained

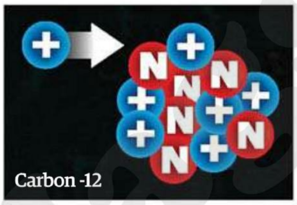
Proton-proton fusion

A nuclear fusion process that fuels stars with core temperatures less than 15 million Kelvin, proton-proton fusion is a common reaction. It entails two protons fusing, with one being transmuted to a neutron, forming deuterium. The deuterium then fuses with another proton, generating a helium nuclei, two of which then fuse to generate an alpha particle and the release of two protons.



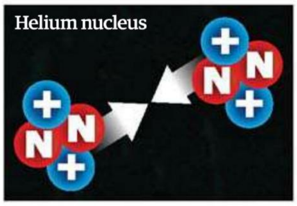
Carbon fusion

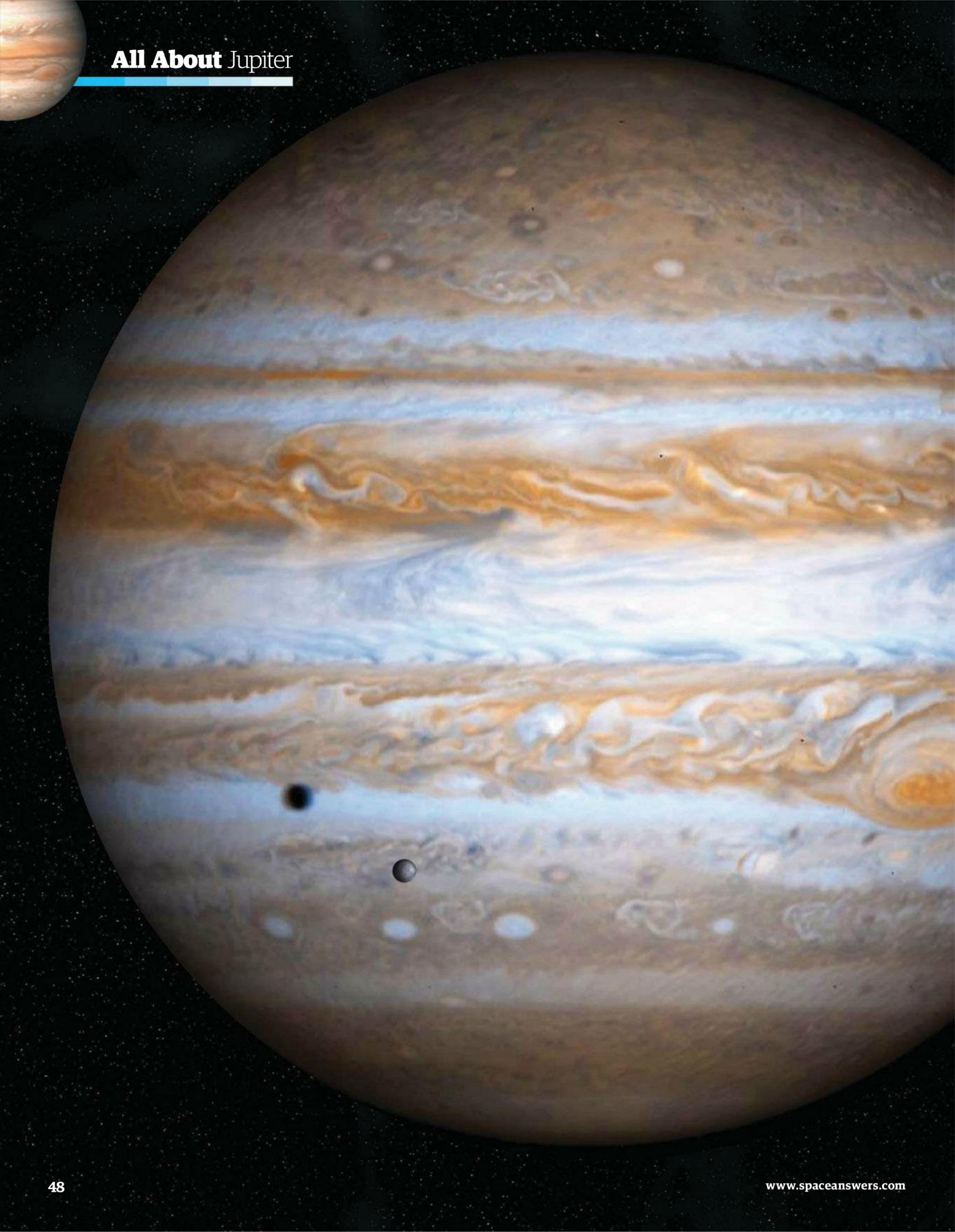
For stars with central temperatures over 15 million Kelvin, carbon fusion tends to be the dominant process. It revolves around adding protons to carbon and then nitrogen over multiple sequences. The end result is the generation of an oxygen-16 atom, which emits an energetic alpha particle. This is not a major part of the Sun's reaction cycle, but is prevalent in the star Sirius.



Helium fusion

If the core temperature of a star exceeds 100 million Kelvin, as is typical of red supergiant stars, then helium-helium can become the dominant reaction. This involves two helium nucleuses fusing to create beryllium-8 and emitting gamma rays, before the beryllium-8 fuses with another helium nucleus and generates carbon-12, which unlike beryllium is stable.





All About... JUPITER

Written by Shanna Freeman

Volatile and violent in nature and named after the Roman king of gods, the largest world in our Solar System has twice the mass of all other planets combined. Discover more about the gas giant that is king of the planets

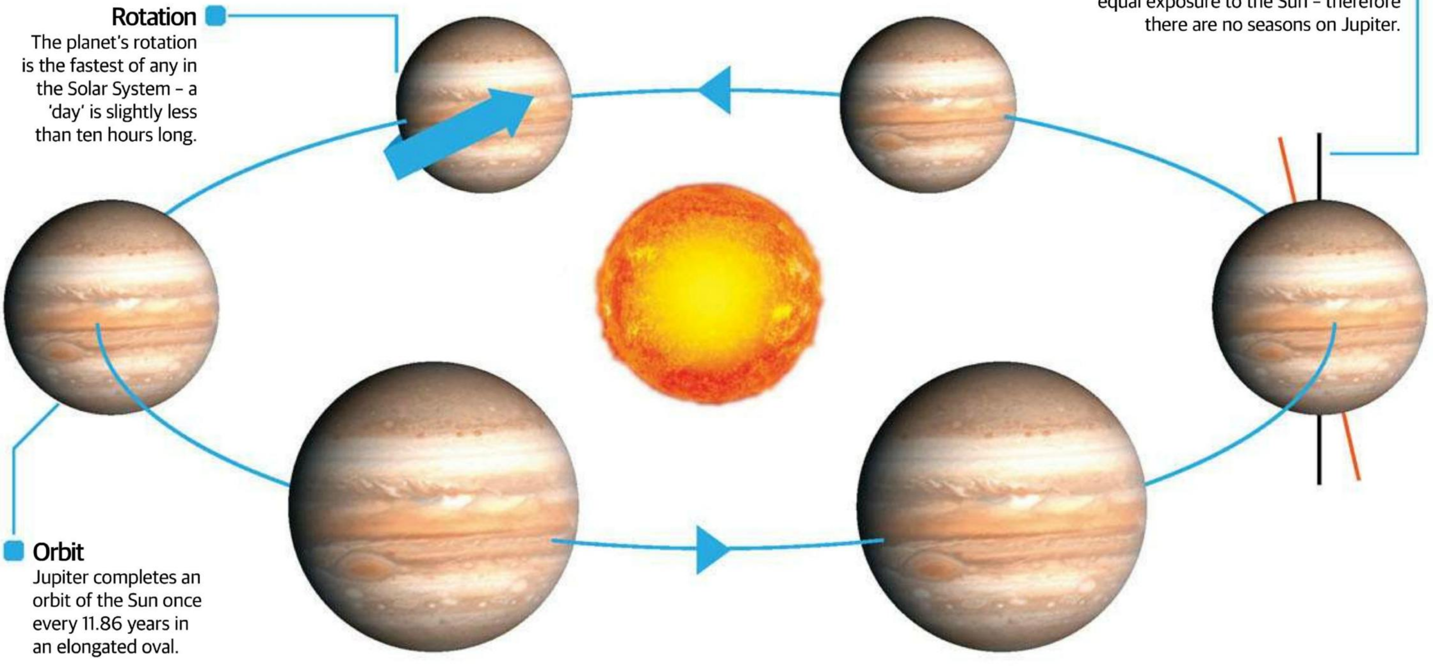
If you had to choose just one word to describe Jupiter, it would have to be 'big'. It has a diameter of 142,984 kilometres (88,800 miles) at its equator, about 11 times that of Earth's diameter. As the largest planet, with a huge magnetic field and 64 moons and natural satellites, Jupiter could almost be a miniature solar system. Sometimes it's even been referred to as a 'failed star' because it's made of the same gases as the Sun – although it doesn't have anywhere near the mass or temperature to actually be a star. Jupiter would need a mass about 80 times that of its current one, and that's never going to happen. But 'star' is how the ancients thought of it, at least until Galileo noticed that the planet had four prominent moons – Callisto, Europa, Ganymede and Io – that moved around it. It was the first time movement in the Solar System not centred on Earth was discovered, which helped cement Copernicus's theory of a heliocentric – or sun-centred – astronomical model.

Jupiter is the innermost of the four gas giants, along with Saturn, Uranus and Neptune – planets that mainly comprise gas and are also more than ten times that of Earth's mass. The gases get denser as you get closer to the planet's core. Since Jupiter is the largest – the next-largest is Saturn with a diameter of 120,536 kilometres (75,000 miles) – it's not surprising that these gas giants are also called the Jovian planets. Jupiter's mass is 317.8 times that of Earth's and 0.001 times that of the Sun's; sometimes planets outside the Solar System are defined in terms of Jupiter's mass because it's so large. What's amazing is that Jupiter was actually larger when it was first formed – it's been shrinking about two centimetres (0.8 inches) per year due to its heating and cooling process. Jupiter's so massive that its barycentre – or centre of mass with the Sun – lies outside the Sun at 1.068 solar radii above its surface. Although Jupiter is large in diameter and mass, it's not very dense thanks to its gaseousness. Jupiter has a density of 1.33 grams per cubic centimetre, which is about 25 per cent that of Earth's density.

Jupiter is 779 million kilometres (484 million miles) from the Sun on average, completing an orbit once every 11.86 years. This is two-fifths the orbit of Saturn, putting the planets in an orbital resonance of 5:2. It has a very small axial tilt of just 3.13 degrees, so there are no seasons on the planet. It has the fastest rotation of all the planets, taking a quick spin on its axis once every ten hours or so. This gives the planet a bulge around its equator and the shape of an oblate spheroid – it has a larger diameter around its centre than its poles. Because Jupiter is a gas

> "With a huge magnetic field and 64 moons it could almost be a miniature solar system"

The gas giant in orbit



Axial tilt
A tilt of 3.13 degrees means that the northern and southern hemispheres get equal exposure to the Sun – therefore there are no seasons on Jupiter.

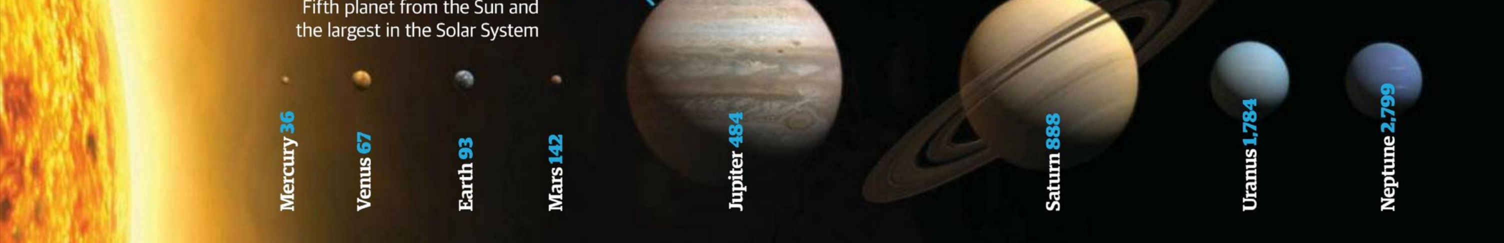
Rotation
The planet's rotation is the fastest of any in the Solar System – a 'day' is slightly less than ten hours long.

Orbit
Jupiter completes an orbit of the Sun once every 11.86 years in an elongated oval.

The planets in relation to the Sun

All figures = million miles from Sun

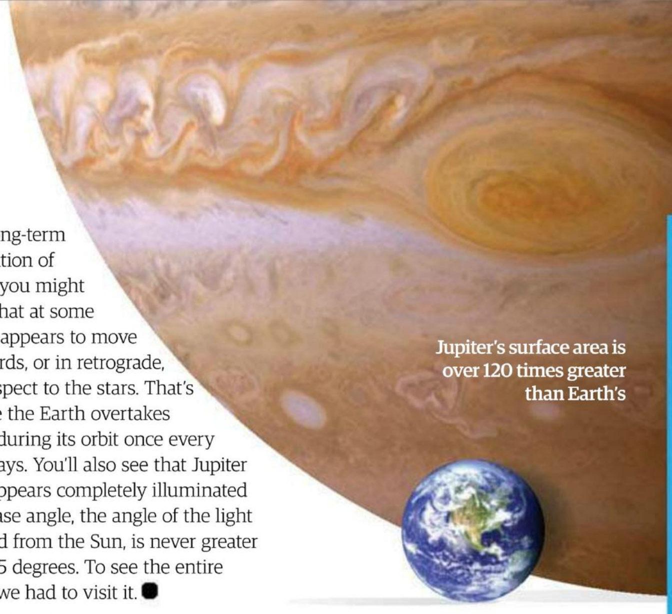
Jupiter lies 779 million km (484 million miles) from the Sun on average, and 629 million km (391 million miles) from Earth



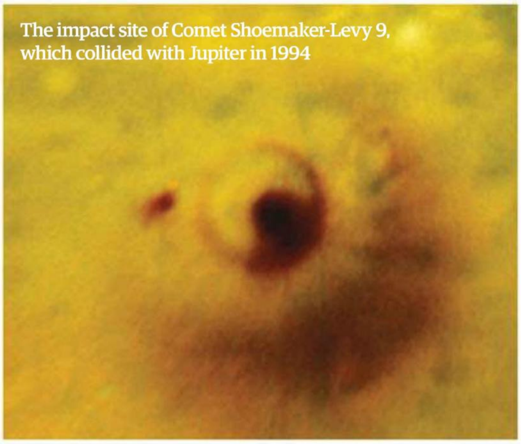
Jupiter
Fifth planet from the Sun and the largest in the Solar System

planet, not all of the planet orbits at the same speed. It basically has three different systems – the atmosphere at the poles rotates about five minutes faster than the equatorial atmosphere, which is a little bit slower than the rotation of the magnetosphere (it clocks in at just under ten hours, the official rotation period).

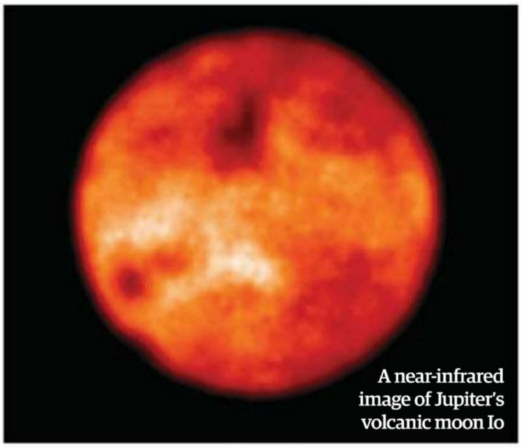
Jupiter is about more than just its size, of course. It has a very striking and unusual appearance, with moving bands of red, orange, white and brown. The planet is the fourth-brightest object in our night sky. If you do some long-term observation of Jupiter, you might notice that at some point it appears to move backwards, or in retrograde, with respect to the stars. That's because the Earth overtakes Jupiter during its orbit once every 398.9 days. You'll also see that Jupiter never appears completely illuminated – its phase angle, the angle of the light reflected from the Sun, is never greater than 11.5 degrees. To see the entire planet, we had to visit it. ■



Jupiter's surface area is over 120 times greater than Earth's

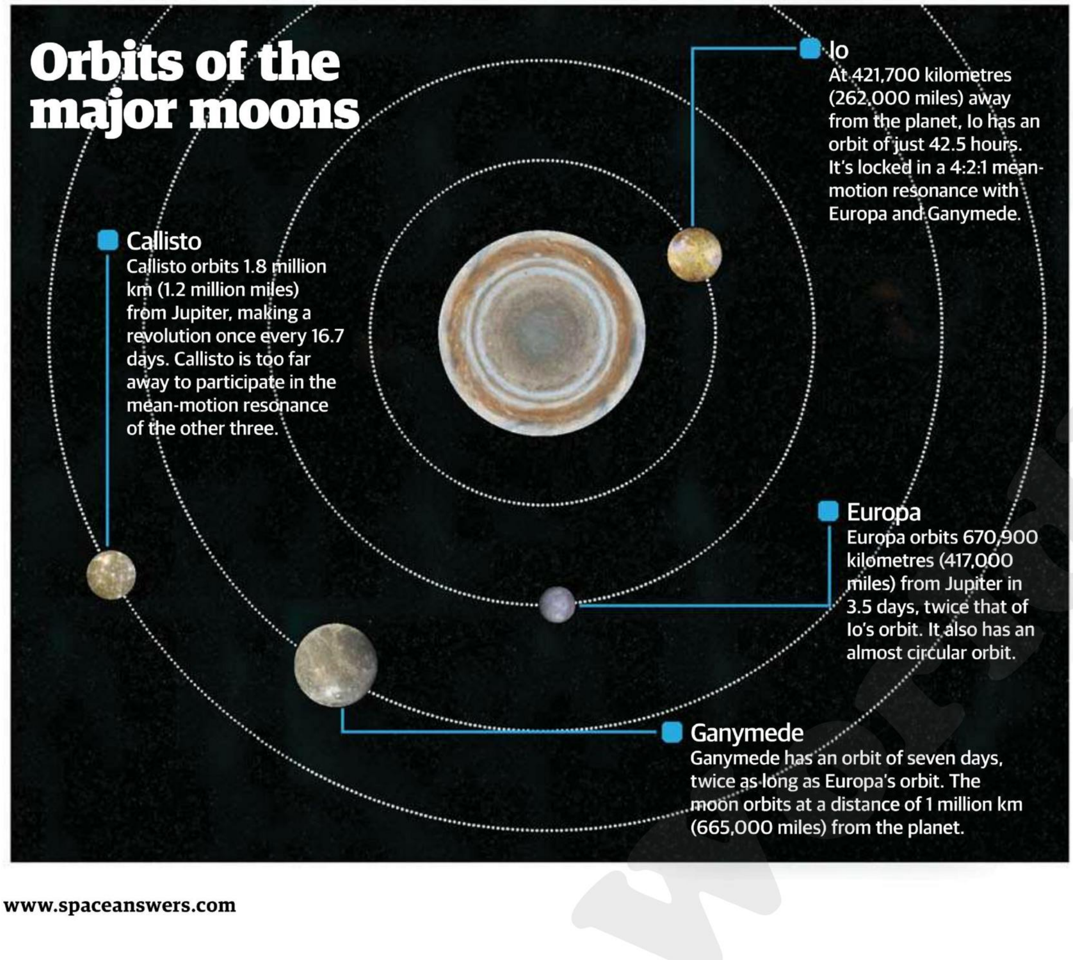


The impact site of Comet Shoemaker-Levy 9, which collided with Jupiter in 1994



A near-infrared image of Jupiter's volcanic moon Io

Orbits of the major moons



Io
At 421,700 kilometres (262,000 miles) away from the planet, Io has an orbit of just 42.5 hours. It's locked in a 4:2:1 mean-motion resonance with Europa and Ganymede.

Callisto
Callisto orbits 1.8 million km (1.2 million miles) from Jupiter, making a revolution once every 16.7 days. Callisto is too far away to participate in the mean-motion resonance of the other three.

Europa
Europa orbits 670,900 kilometres (417,000 miles) from Jupiter in 3.5 days, twice that of Io's orbit. It also has an almost circular orbit.

Ganymede
Ganymede has an orbit of seven days, twice as long as Europa's orbit. The moon orbits at a distance of 1 million km (665,000 miles) from the planet.

The Galilean moons

Io

Io is the innermost of the Galilean moons, and also the fourth-largest moon in the Solar System at 3,642 kilometres (2,200 miles) in diameter. Unlike most moons, Io is mainly silicate rock and has a molten core. That's probably why it has more than 400 active volcanoes, making it the most volcanically active body – moon or planet.

Europa

The second-closest Galilean moon to Jupiter, Europa is also the smallest of the four moons. It's slightly smaller than our own Moon with a diameter of around 3,100 kilometres (1,940 miles). It has a smooth surface of ice and probably has a layer of liquid water underneath, leading to theories that life may be able to exist on this moon.

Ganymede

Ganymede is the largest moon in the Solar System – at 5,268 kilometres (3,300 miles), it's actually larger than the planet Mercury, although it has half the mass. This moon is also the only known moon with a magnetosphere, probably due to a liquid iron core. This moon also comprises both ice and silicate rock, and it's believed that there may be a saltwater ocean below the surface.

Callisto

Being the outermost Galilean moon, Callisto is furthest from Jupiter and its strong radiation and therefore might be a good base for exploring the planet. The moon is composed equally of water-ice and rock, and there's also the possibility that it may be able to support life. It has a heavily cratered surface as well as a thin atmosphere, which is most likely composed of oxygen and carbon dioxide.

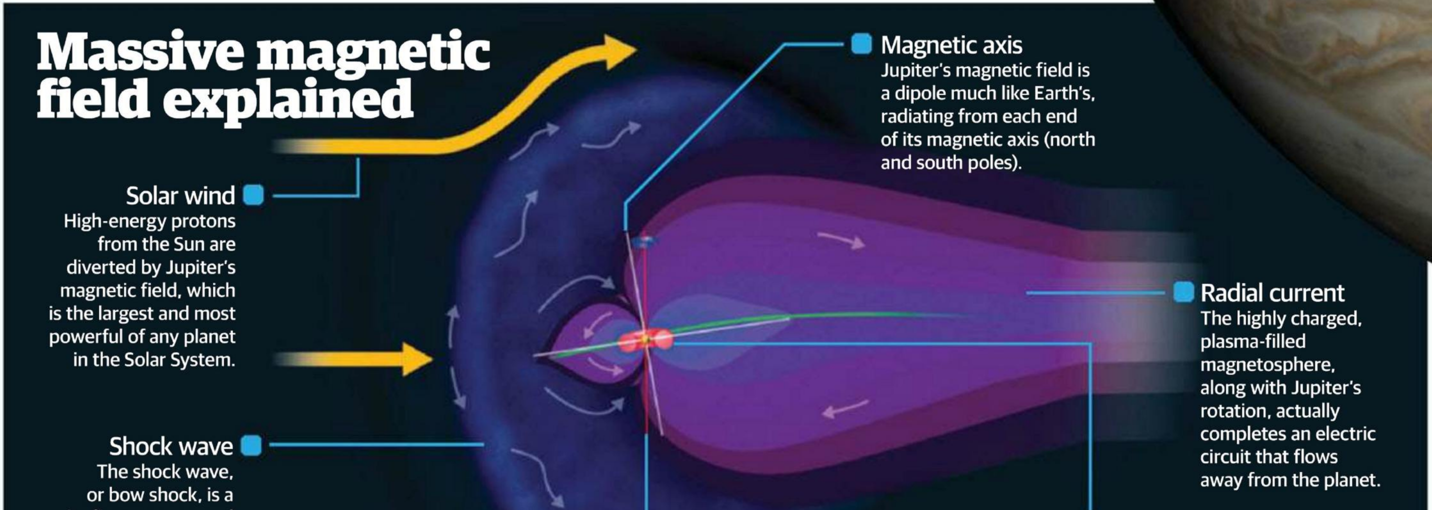
Jupiter inside and out

A rocky core surrounded by liquid metallic hydrogen, Jupiter gets more interesting the closer you get to its centre

Since Jupiter is a gaseous planet, it's mostly about atmosphere. The gases just get denser, hotter and under greater pressures as you go further towards the centre. Jupiter is about 90 per cent hydrogen and ten per cent helium – volume-wise. But if you measure the composition of the planet by mass, there's 75 per cent hydrogen and 24 per cent helium. There are also traces of ammonia, methane, carbon, hydrogen sulphide and other elements and compounds. We don't know that much about the interior because no probe has penetrated the cloud cover below 150 kilometres (93 miles). But we do think that Jupiter isn't entirely gaseous; we believe it has a rocky core containing silicates and other elements, with a mass that is 10 to 15 times that of Earth's mass. The concept of a rocky core is based on gravitational measurements taken by probes, but this model is very uncertain until we get more data from NASA's Juno mission (set to enter Jupiter's orbit in 2016). Current projections for the interior show a layer of liquid metallic hydrogen along with helium surrounding the core, with a layer of molecular hydrogen outside. There is no actual boundary between the liquid and gaseous layers, however.

Temperatures on Jupiter vary widely. In the cloud layer, they are very cold at -145 degrees Celsius (-234 degrees Fahrenheit). As you move further towards the core, as the hydrogen becomes liquid, the temperature reaches 9,700 degrees Celsius (17,500 degrees Fahrenheit), and the core may be as hot as 30,000 degrees Celsius (54,000 degrees Fahrenheit). The planet is thought to have been much hotter and also much bigger – as much as twice its current diameter – when it first formed. Jupiter generates almost as much heat on its own as it receives from the Sun, via a process called the Kelvin-Helmholtz mechanism. The surface cools, which also results in a loss of pressure. The whole planet shrinks, which compresses the core and causes it to heat up. The pressure at the core may be up to 4,000 GPa (gigapascals). By comparison the Earth's core is at a pressure of 360 GPa. The pressure inside Jupiter is so intense that some scientists believe that the core may actually be gradually liquefying. ■

Massive magnetic field explained



Magnetic axis
Jupiter's magnetic field is a dipole much like Earth's, radiating from each end of its magnetic axis (north and south poles).

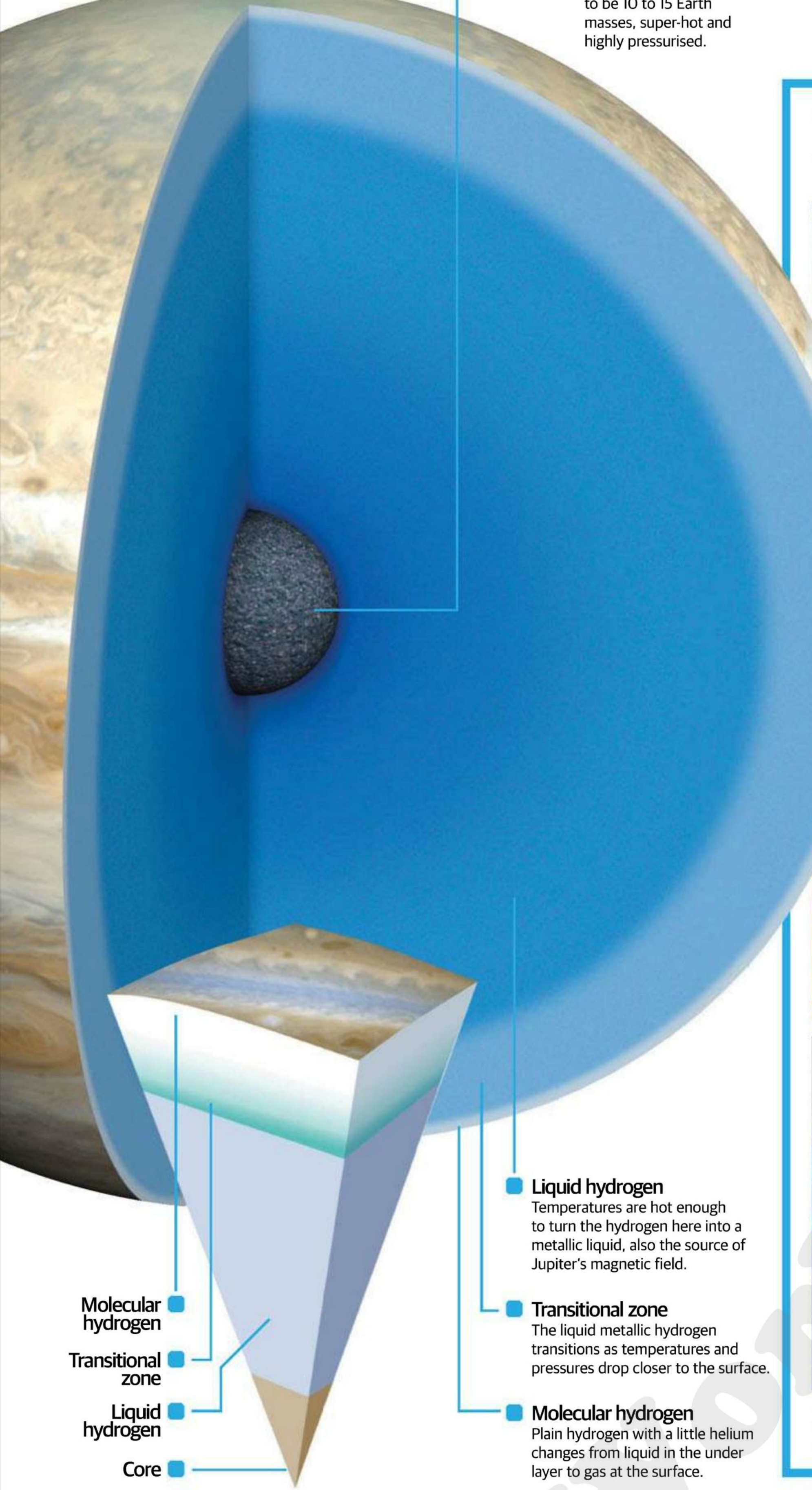
Solar wind
High-energy protons from the Sun are diverted by Jupiter's magnetic field, which is the largest and most powerful of any planet in the Solar System.

Radial current
The highly charged, plasma-filled magnetosphere, along with Jupiter's rotation, actually completes an electric circuit that flows away from the planet.

Shock wave
The shock wave, or bow shock, is a rippling wave caused by the interaction between the solar wind and the magnetic field.

Rotation axis
The axis upon which the planet turns is only slightly different from its magnetic axis, due to a very small tilt.

Plasma torus
Volcanic activity on the moon Io causes large amounts of plasma to build up around Jupiter, affecting its magnetosphere far more than the solar wind.



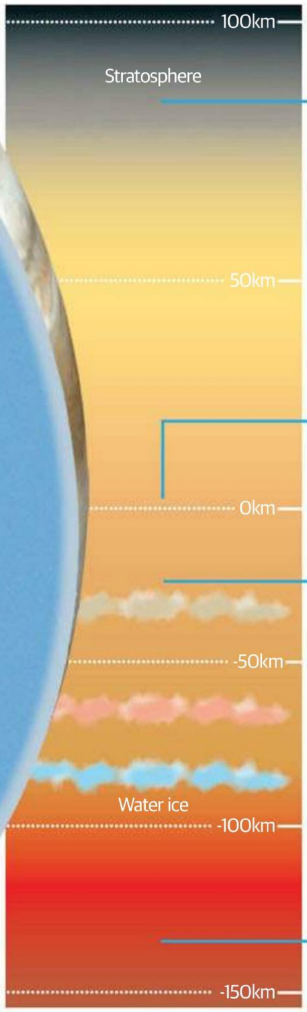
Core
This rocky core is believed to be 10 to 15 Earth masses, super-hot and highly pressurised.

Liquid hydrogen
Temperatures are hot enough to turn the hydrogen here into a metallic liquid, also the source of Jupiter's magnetic field.

Transitional zone
The liquid metallic hydrogen transitions as temperatures and pressures drop closer to the surface.

Molecular hydrogen
Plain hydrogen with a little helium changes from liquid in the under layer to gas at the surface.

The structure of the atmosphere

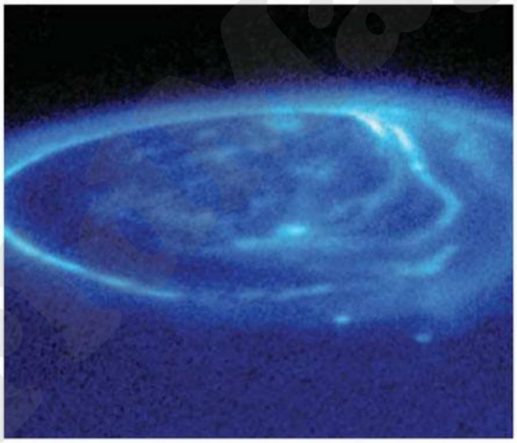


Stratosphere
The stratosphere is still mostly hydrogen, with methane, ethane, acetylene and other light hydrocarbons.

Haze layer
Above the cloud layer there's a layer of hydrazine haze, made by interactions between ultraviolet radiation from the Sun and methane in the stratosphere.

Troposphere
The upper clouds are the lightest, of ammonia, and get denser as they change to ammonium hydrosulphide, then to water.

Gas layer
The 'surface' of the planet is defined by pressure and temperature – both begin to drop as the gases dissipate.



Jupiter has auroras just like Earth – charged particles from the solar wind interact with the planet's magnetic field, resulting in a glowing display

In the clouds

It might not have a surface, but the clouds of Jupiter are a fascinating phenomena

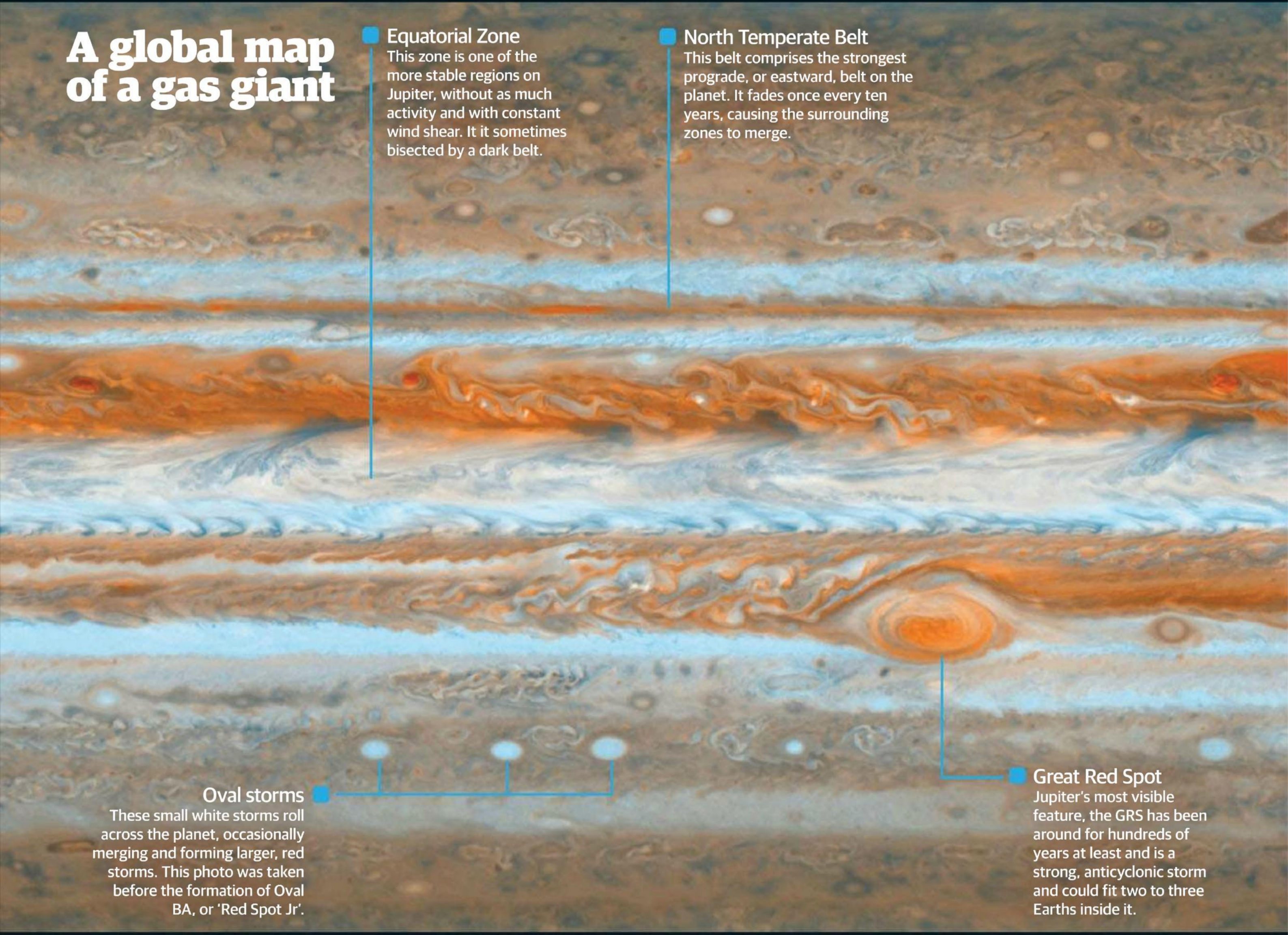
The colours visible in photos of Jupiter are a result of the different layers of clouds in the planet's atmosphere. The cloud layers aren't static, either – they move and flow in complex patterns. The approximately dozen lines are called bands, and there are two different kinds: the lighter-coloured areas are known as zones, while the dark-coloured ones are called belts.

Zones comprise dense, ammonia ice clouds in higher areas and are colder, while the dark belts contain thinner, lower, warmer clouds. Their red and orange colours come from sulphur and phosphorous, while carbon may create some of the lighter grey colours.

The equator is circled by a zone, known as the Equatorial Zone (EZ), that stretches from seven degrees north and seven degrees south of the equatorial line. There are dark Equatorial Belts (EB) extending from the EZ at 18 degrees north and south on either side. Tropical zones are on either side of each EB. The zones and belts then alternate until reaching each of the poles, where they become more difficult to distinguish. None of them have perfect boundaries. Many of the belts and zones have names, each with distinctive features and movements. While most have remained fairly constant for as long as we've been observing and recording them, there are both temporary and permanent changes in things like features, appearance and wind speed. Sometimes the Equatorial Zone is bisected by a dark band, and irregular dark areas known as 'hot spots' can come and go.

Each belt is surrounded by wind jets, called zonal atmospheric flows. The transitional areas from the belts to the zones (headed towards the equator) are marked by westward, or retrograde jets. Eastward, or prograde jets, mark the transitions from zones to belts heading away from the equator. These are more powerful than the retrograde jets, and can reach speeds of up to 100 metres per second or 328 feet per second (360

A global map of a gas giant



Equatorial Zone
This zone is one of the more stable regions on Jupiter, without as much activity and with constant wind shear. It it sometimes bisected by a dark belt.

North Temperate Belt
This belt comprises the strongest prograde, or eastward, belt on the planet. It fades once every ten years, causing the surrounding zones to merge.

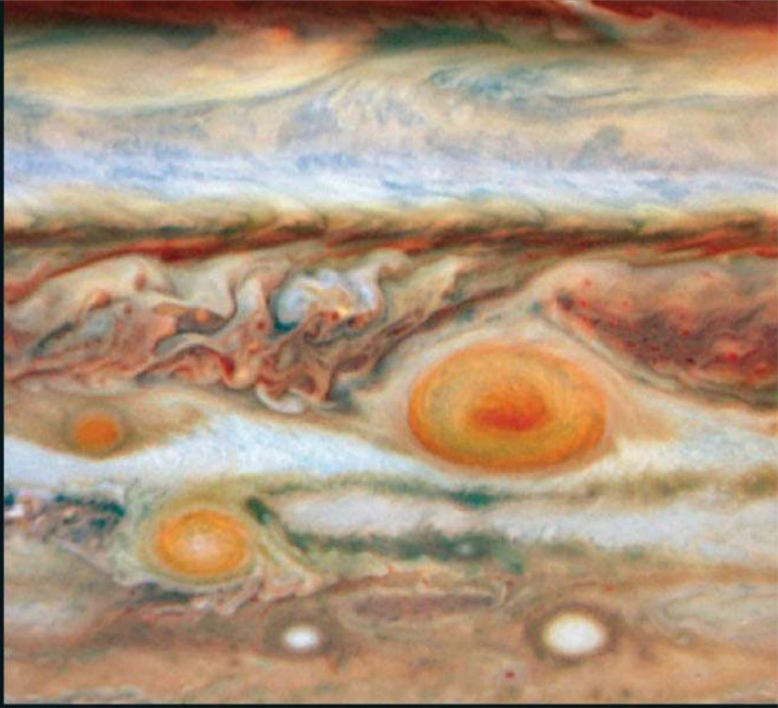
Oval storms
These small white storms roll across the planet, occasionally merging and forming larger, red storms. This photo was taken before the formation of Oval BA, or 'Red Spot Jr'.

Great Red Spot
Jupiter's most visible feature, the GRS has been around for hundreds of years at least and is a strong, anticyclonic storm and could fit two to three Earths inside it.

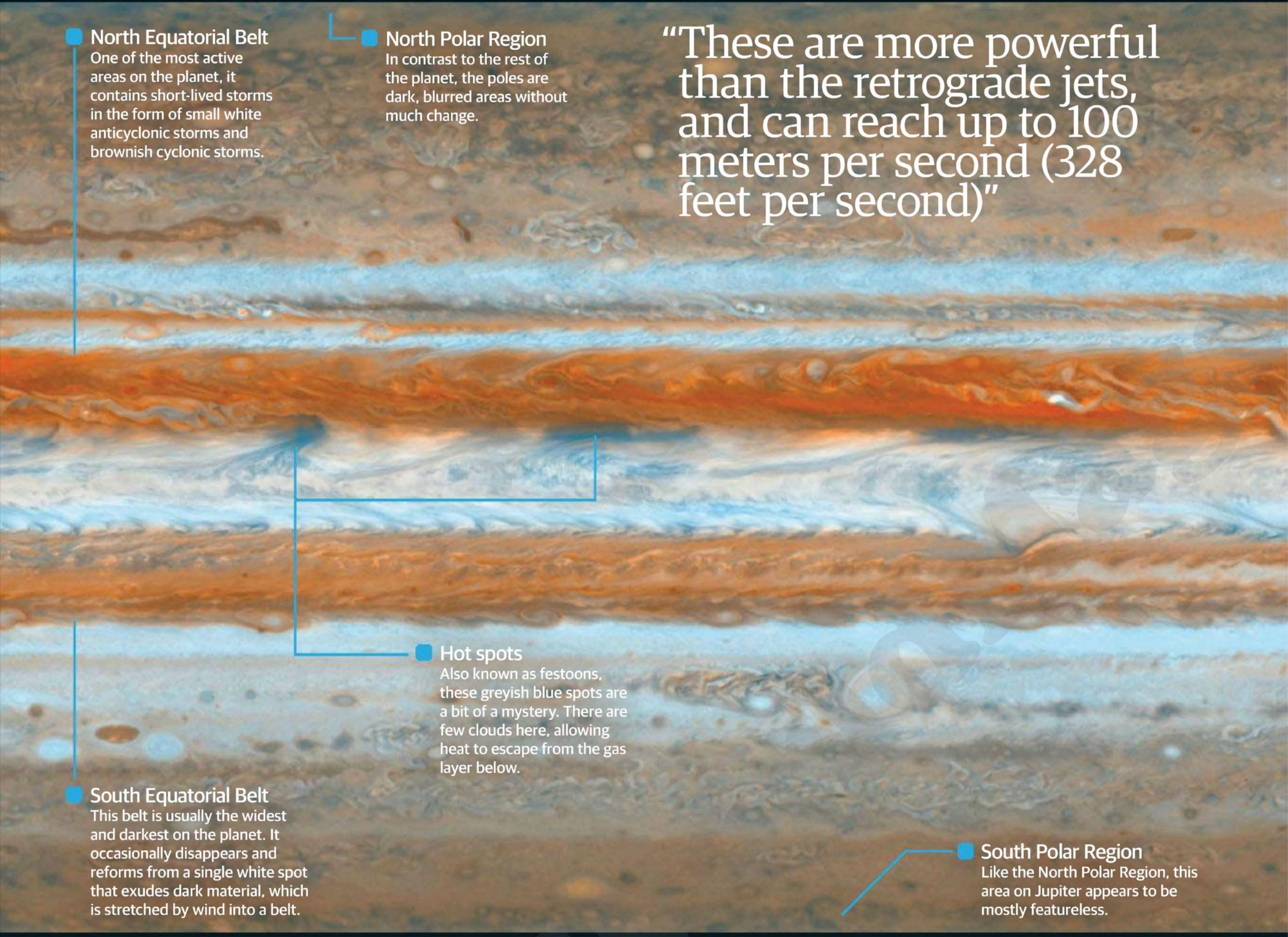
kilometres per hour or 224 miles per hour). In the belts, the wind shear is cyclonic – the air flows in the same direction as Jupiter's rotation. Zone wind shear, however, is anticyclonic. The exception to these rules is the Equatorial Zone – it has a prograde jet with very little movement right along the equator.

We do not yet know exactly how deep the jets go, but we do know that they exist as far down as the Galileo probe was able to measure, about 150 kilometres (93 miles) below the top of the clouds. We're also not sure what causes this band structure on Jupiter, but one theory is that the belts are areas of downwelling (higher density material sinking beneath lower density material), while the zones are areas of upwelling. The ice clouds rich in ammonia cool and expand, causing the dense light-coloured clouds in the zones. In the belts, the same clouds warm and eventually evaporate. This allows the darker, mineral-laden clouds below to show through.

While Jupiter doesn't have seasons because of its small axial tilt, it does have weather patterns. The evaporation and condensation process of water creates dense clouds. These are strong storms, including powerful lightning strikes, mainly in the belts. Most storms on Jupiter tend to be very short, but there are a few major storms that have been raging for a long time. The biggest and most well-known of these is the Great Red Spot, which has been around for a minimum of between 180 and 300 years, and there's also the Oval BA storm (which is sometimes referred to as 'Red Spot Jr').



The Great Red Spot and Oval BA got some company in 2008 when small white oval storms merged and formed a new red spot (on the far left). Its appearance may mean that Jupiter is undergoing climate change and warming near its equator



> "These are more powerful than the retrograde jets, and can reach up to 100 meters per second (328 feet per second)"

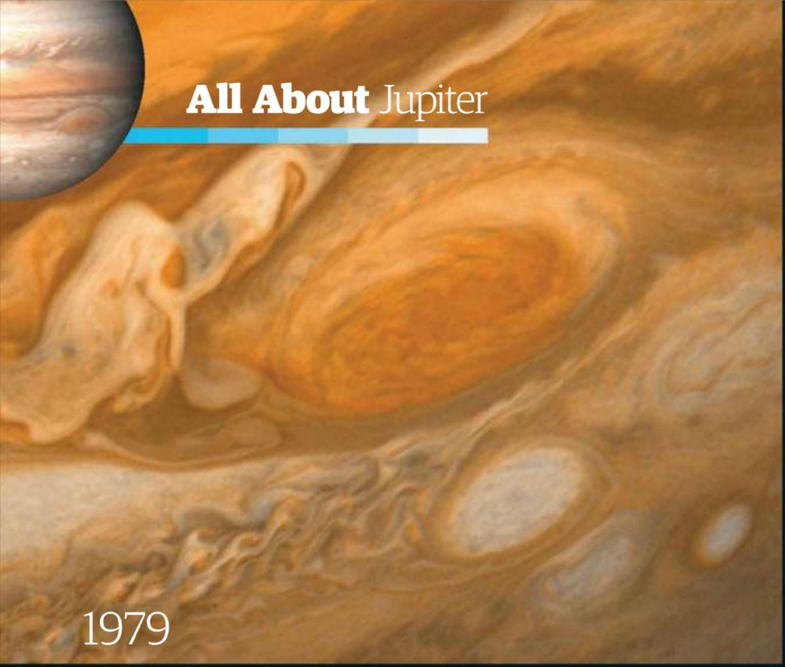
North Equatorial Belt
One of the most active areas on the planet, it contains short-lived storms in the form of small white anticyclonic storms and brownish cyclonic storms.

North Polar Region
In contrast to the rest of the planet, the poles are dark, blurred areas without much change.

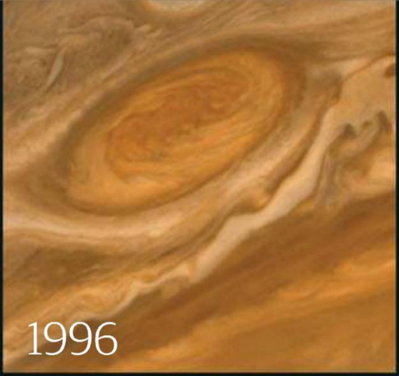
Hot spots
Also known as festoons, these greyish blue spots are a bit of a mystery. There are few clouds here, allowing heat to escape from the gas layer below.

South Equatorial Belt
This belt is usually the widest and darkest on the planet. It occasionally disappears and reforms from a single white spot that exudes dark material, which is stretched by wind into a belt.

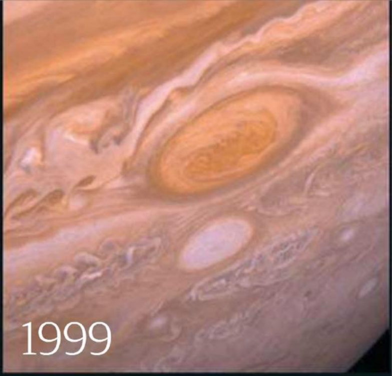
South Polar Region
Like the North Polar Region, this area on Jupiter appears to be mostly featureless.



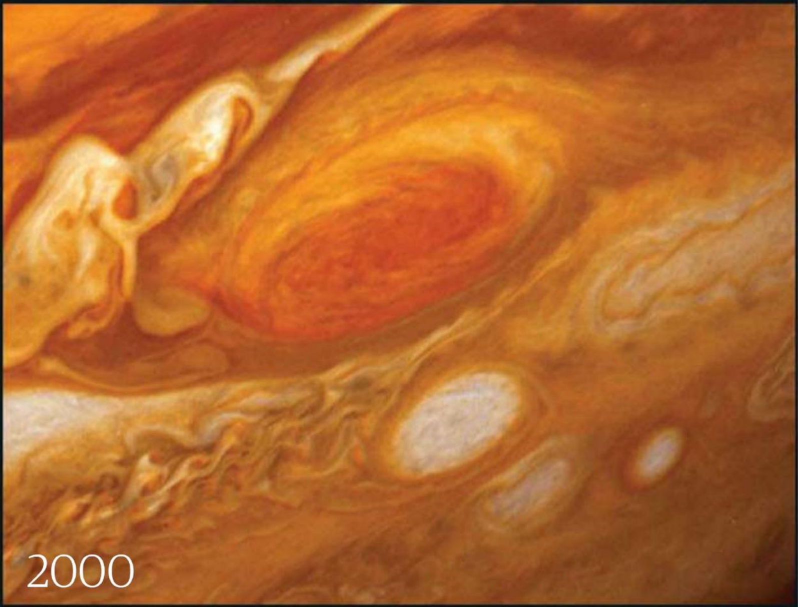
1979



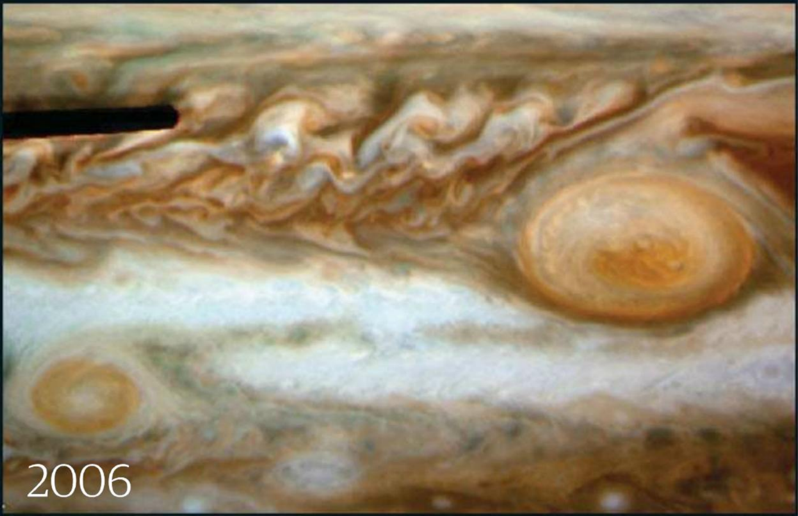
1996



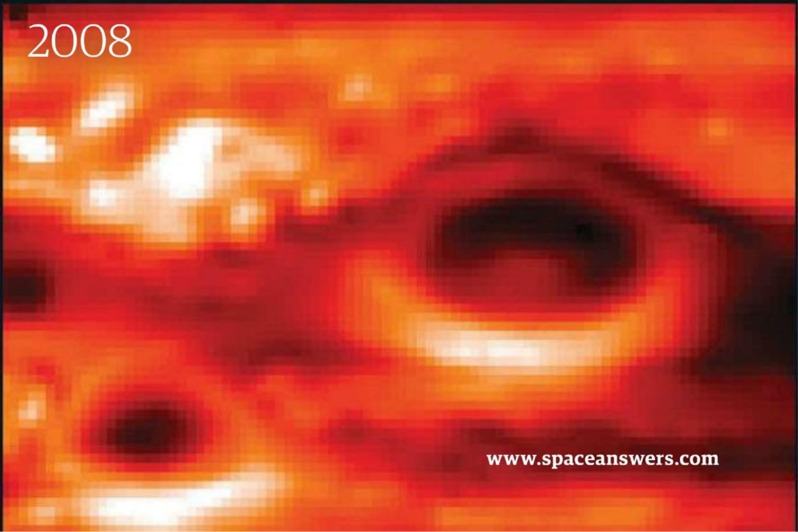
1999



2000



2006



2008

The changing Great Red Spot

A storm with the circumference of Earth that's raged for centuries

Sometimes our storms seem like they're never going to end, but imagine a storm that's been going for hundreds of years. The Great Red Spot is a dark red, anticyclonic storm with high pressure.

It is currently between 12,000 and 14,000 kilometres (7,500 to 8,700 miles) wide north to south and 24,000 to 40,000 kilometres (15,000 to 25,000 miles) east to west. Some data suggests that it was originally much bigger, but its shrinkage doesn't mean that it's disappearing.

The clouds that make up the GRS are higher – at least eight kilometres (five miles) – and therefore colder than the surrounding clouds. Its darkest, reddest area in the centre is significantly warmer than the rest, and actually has a mild clockwise rotation. The colours of the GRS vary wildly – sometimes they're strong, dark reds and oranges, other times, it gets so pale that it disappears, leaving a sort of niche behind in the South Equatorial Belt until it reappears. The colour is linked to that of the SEB – when the GRS is darker, the SEB tends to be lighter, and vice versa. Why has the Great Red Spot lasted so long? We can't be sure, but one theory is that it's continually powered by the intense heat from the planet, there's no landmasses or other formations to disrupt it. It has also absorbed smaller storms in the past. ●

1979
Taken by Voyager 1, this image of the GRS shows details of the storm's cloud patterns. The wavy pattern on the left is due to variable wave motion. The white spot visible has a diameter roughly equivalent to Earth's.

1996
Another white storm in this image trails along with the GRS, which is at a more elongated and salmon-coloured stage. Note that the equatorial belt in which it resides is about the same colour.

1999
The storm and its belt are still about the same colour, but the GRS appears to be getting darker and the belt, lighter. This image also shows two of the three white spots that would eventually become the Oval BA.

2000
This Hubble image shows a darker and more compact GRS. It also features the Oval BA, or 'Red Spot Jr.' A similar merger centuries ago may have created the original GRS.

2006
This image taken by Hubble shows a darker and more compact GRS. It also reveals the Oval BA.

2008
Obtained by the VLT, this image was taken in an infrared wavelength which is sensitive to Jupiter's atmospheric temperatures in the 300 to 600 millibar pressure range.

A hidden ring system

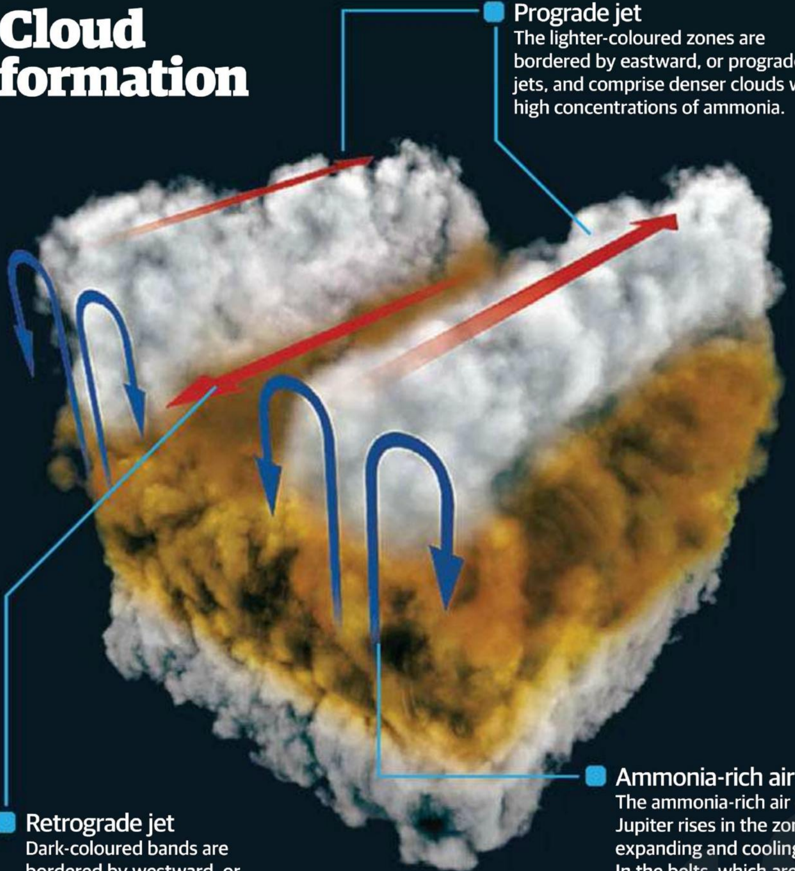
When it comes to rings in our Solar System, Uranus and Saturn get all the attention. But it turns out that Jupiter has a ring system of its own. It was first discovered by the Voyager 1 probe in 1979, while Galileo revealed more about the rings in the Nineties.

The Jovian ring system consists mainly of dust and has four main components. The two outer rings are wide, faint and named after the moons that connect them. The Thebe gossamer ring is 97,000km (60,300 miles) wide and has a radius of 129,000km (80,200 miles) to 226,000km (140,400 miles), while the next ring is the Amalthea gossamer, with a width of 53,000km (32,900 miles) and a radius of 129,000km (80,200 miles) to 182,000km (113,000 miles).

The main ring is the thinnest, but also the brightest. It has a radius of 122,500km (76,100 miles) to 129,000km (80,200 miles) and is just 6,500km (4,000 miles) wide.

The inner ring is a halo at 30,500km (18,600 miles) wide and with a radius of 92,000km (57,200 miles) to 122,500 km (76,100 miles). While the other rings look reddish, the halo ring appears blue and is the thickest ring. The other rings are made up of particles coming off the tiny moons located within them, while the halo ring is likely formed from particles sucked towards the planet from the main ring.

Cloud formation



Prograde jet
The lighter-coloured zones are bordered by eastward, or prograde jets, and comprise denser clouds with high concentrations of ammonia.

Retrograde jet
Dark-coloured bands are bordered by westward, or retrograde jets, comprising low clouds high in sulphuric compounds.

Ammonia-rich air
The ammonia-rich air on Jupiter rises in the zones, expanding and cooling. In the belts, which are warmer, the ammonia evaporates and reveals the dark cloud layer below.

Jupiter by numbers

Fantastic figures and surprising statistics about the gas giant

1,321

This is how many Earths could fit inside Jupiter

2.4 times

How much more you would weigh on Jupiter if you could stand on it, due to its stronger gravity

64

Of Jupiter's 64 natural satellites, most of them measure less than five kilometres (3.1 miles)

1st

The Galilean moons of Jupiter were the first objects in the Solar System discovered by telescope

318 times

The mass of Jupiter is 318 times greater than the mass of Earth and 2.5 times that of all the other planets in our Solar System combined

50km

The thickness of the clouds and storms on the planet

Exploring a gas giant

Sending back pictures from the outer Solar System

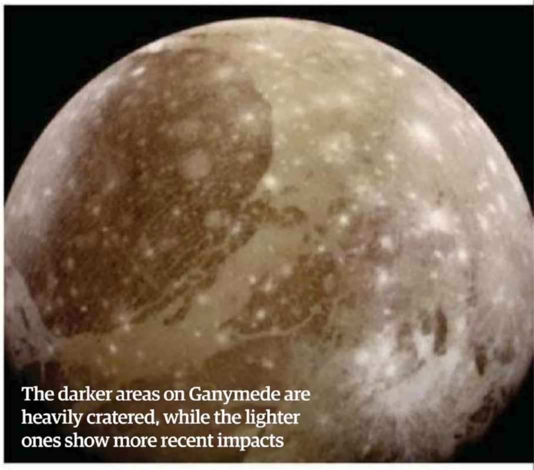
Although we've been observing the gas giant since the time of the ancient Babylonians, we only really began to learn about the planet's wonders when NASA sent the Pioneer 10 space probe to take a closer look in 1973.

The probe became the first spacecraft to traverse the asteroid belt and upon getting close to Jupiter, it began sending back the most detailed images of the planet that we had ever seen. They were being shown in real time back on Earth, and it was so impressive that NASA would later win an Emmy for its presentation. Pioneer 10 also sent back images of the Galilean moons Europa and Ganymede, although they were blurry and not as detailed due to the distance. The closest Pioneer 10 got to the planet was 132,252 kilometres (82,000 miles), at which time it took detailed, close-up images of the Great Red Spot. Communication between Earth and Pioneer 10 was eventually lost in 2003 with the probe at a distance of 12 billion kilometres (7.5 billion miles) from Earth. Pioneer 11, launched a little over a year after Pioneer 10, came even closer to the planet at 42,828 kilometres (26,600 miles) and took a number of even more detailed images.

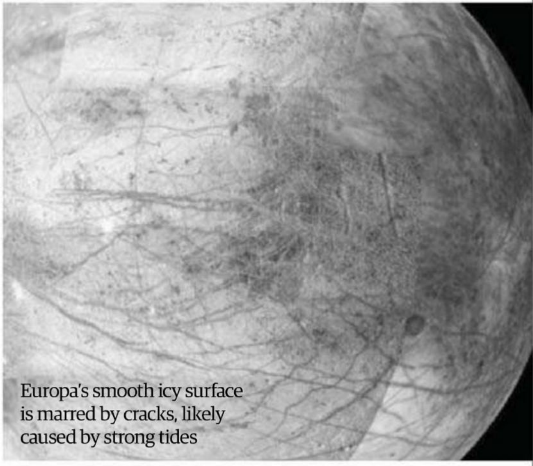
Voyagers 1 and 2, which launched in 1977, made some important discoveries and brought us even better images (see the 'Flight of the Voyager' boxout). However, the most significant Jovian mission to date has been NASA's Galileo – the first and only spacecraft to orbit the planet. Launched in 1989, Galileo not only vastly expanded our knowledge of Jupiter and its moons from orbit, but it also sent a probe down through the atmosphere. The probe revealed more details about the planet's complex cloud system, and also the huge scale of its thunderstorms. Galileo showed that the volcanoes on Io are more active than those on Earth. Ganymede was found to have a magnetic field, and both Europa and Callisto are now believed to have oceans underneath their surfaces as a result of data from Galileo. The mission lasted until 2003 when Galileo was destroyed in a controlled impact with Jupiter.

In 2000, the Cassini-Huygens probe, on its way to Saturn, took the time to capture more than 25,000 images of Jupiter, including the most detailed colour image ever taken. Cassini also made some important discoveries about cloud circulation in the planet's belts and zones. The New Horizons probe, on its way to Pluto, made a stop in 2007 and sent back more images and info. NASA's current mission is the probe Juno. Launched in 2011, it is scheduled to enter Jupiter's orbit in 2016. ■

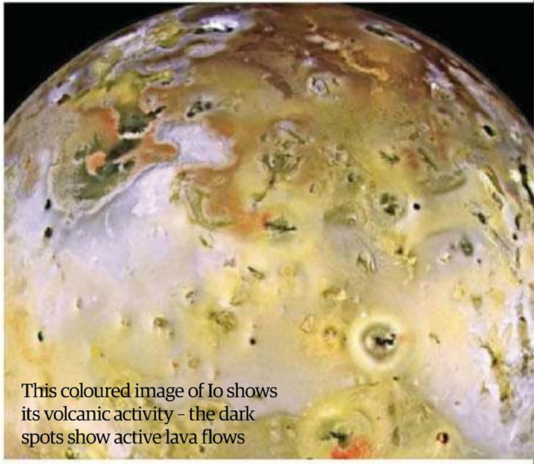
> "Galileo not only vastly expanded our knowledge of Jupiter and its moons from orbit, it also sent a probe down through the atmosphere"



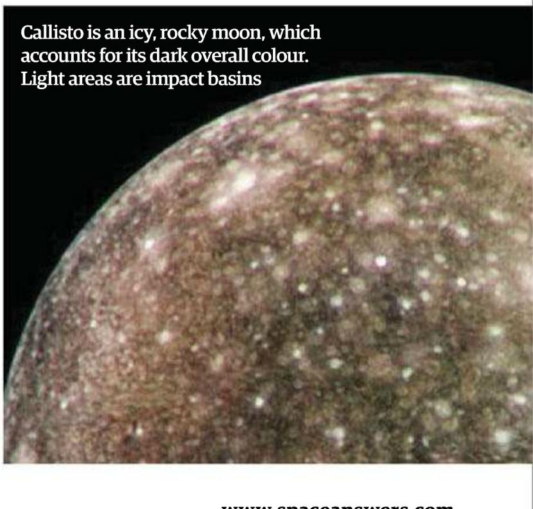
The darker areas on Ganymede are heavily cratered, while the lighter ones show more recent impacts



Europa's smooth icy surface is marred by cracks, likely caused by strong tides

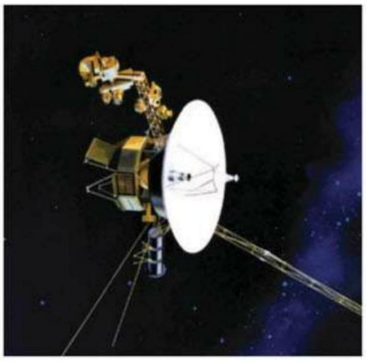


This coloured image of Io shows its volcanic activity – the dark spots show active lava flows



Callisto is an icy, rocky moon, which accounts for its dark overall colour. Light areas are impact basins

Flight of the Voyager



Comprising two different probes, Voyager 1 and Voyager 2, NASA's Voyager programme was launched in 1977. The launches were timed to take advantage of a favourable alignment between the planets that only happens once every 177 years, allowing a single probe to visit Jupiter as well as Saturn, Uranus and Neptune. Voyager 2 was launched first, on 20 August 1977. It came within 570,000km (350,000 miles) of Jupiter on 9 July 1979 and set about making some important discoveries, such as volcanic activity on Io, the ring system and some new moons. Voyager 1 began sending back photos in 1979. These images revealed details of Jupiter's radiation belts, its rings and the Great Red Spot.

Galileo – the first to orbit Jupiter

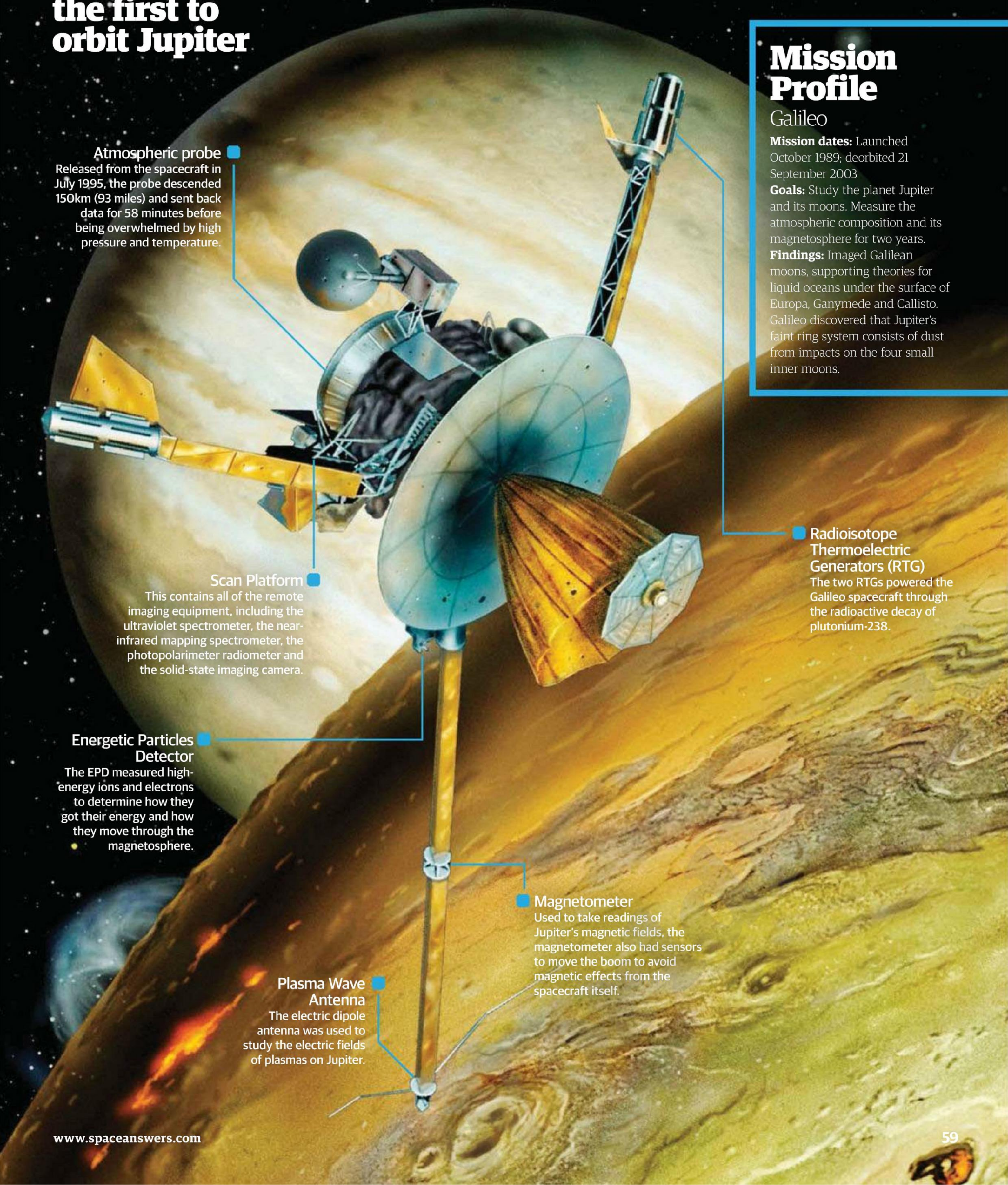
Mission Profile

Galileo

Mission dates: Launched October 1989; deorbited 21 September 2003

Goals: Study the planet Jupiter and its moons. Measure the atmospheric composition and its magnetosphere for two years.

Findings: Imaged Galilean moons, supporting theories for liquid oceans under the surface of Europa, Ganymede and Callisto. Galileo discovered that Jupiter's faint ring system consists of dust from impacts on the four small inner moons.



Atmospheric probe
Released from the spacecraft in July 1995, the probe descended 150km (93 miles) and sent back data for 58 minutes before being overwhelmed by high pressure and temperature.

Radioisotope Thermoelectric Generators (RTG)
The two RTGs powered the Galileo spacecraft through the radioactive decay of plutonium-238.

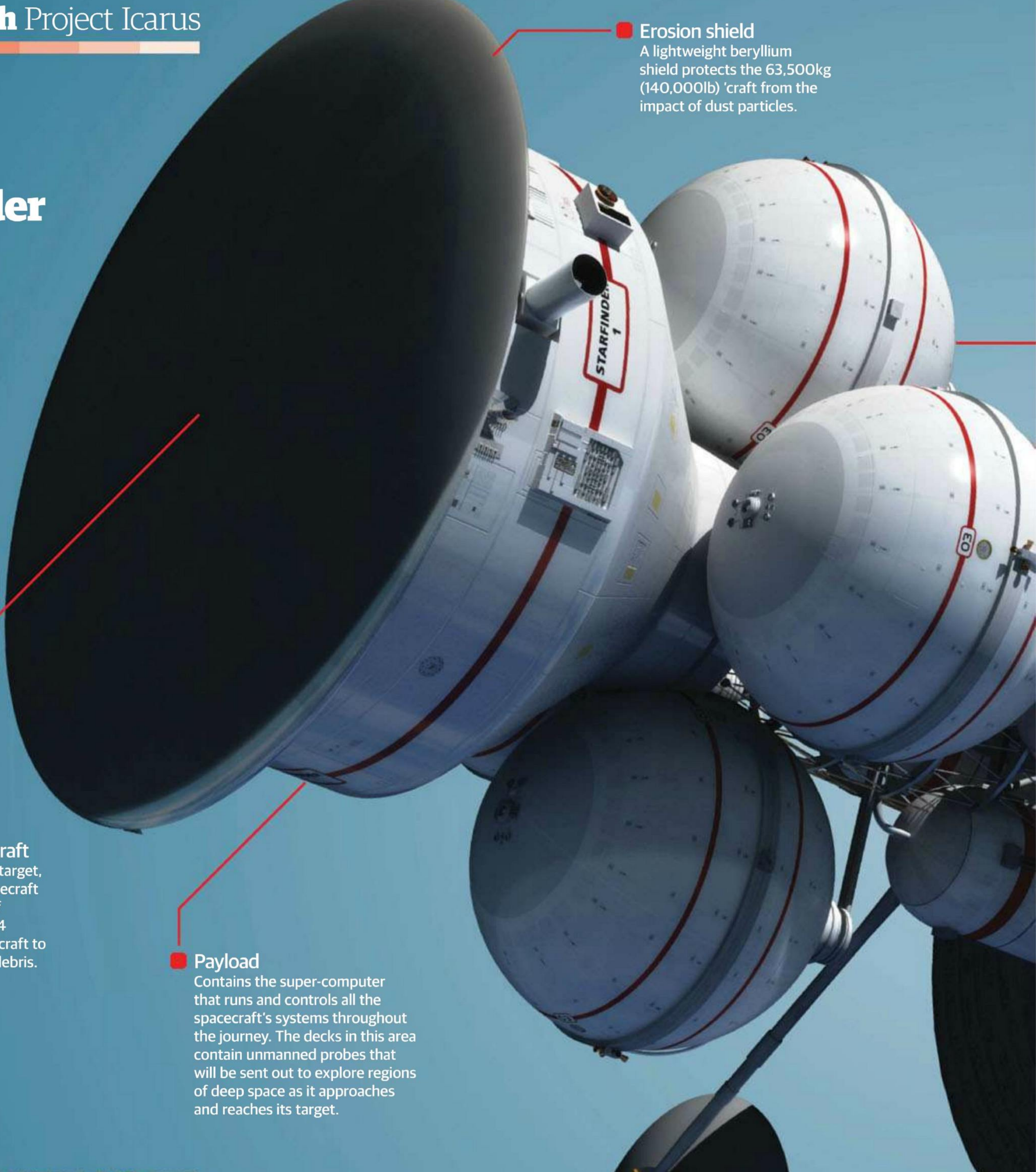
Scan Platform
This contains all of the remote imaging equipment, including the ultraviolet spectrometer, the near-infrared mapping spectrometer, the photopolarimeter radiometer and the solid-state imaging camera.

Energetic Particles Detector
The EPD measured high-energy ions and electrons to determine how they got their energy and how they move through the magnetosphere.

Magnetometer
Used to take readings of Jupiter's magnetic fields, the magnetometer also had sensors to move the boom to avoid magnetic effects from the spacecraft itself.

Plasma Wave Antenna
The electric dipole antenna was used to study the electric fields of plasmas on Jupiter.

Project Icarus Starfinder MkI



Erosion shield
A lightweight beryllium shield protects the 63,500kg (140,000lb) 'craft from the impact of dust particles.

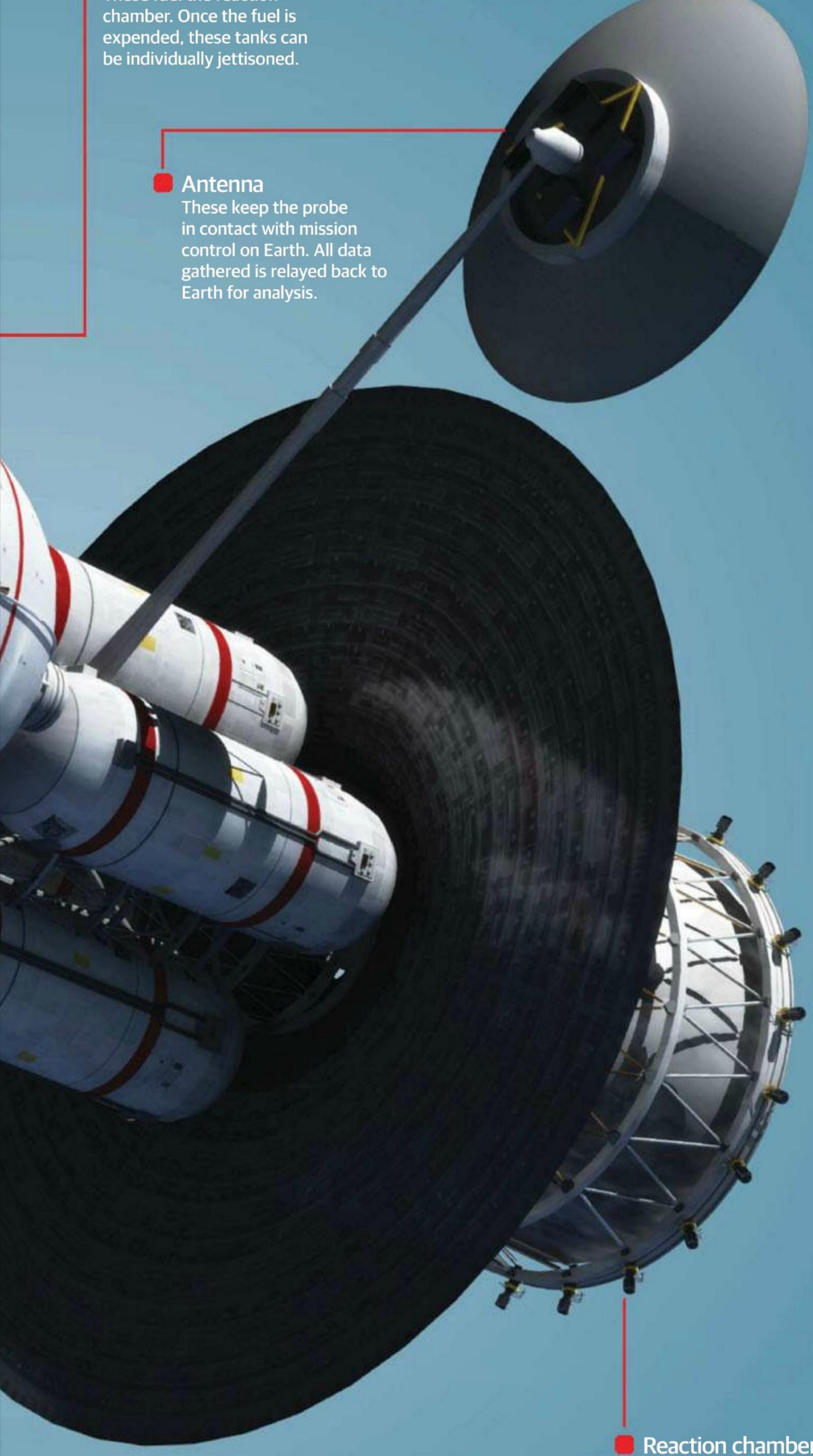
Dustbug Spacecraft
As it approaches its target, small 'Dustbug' spacecraft could seed clouds of particles 200km (124 miles) ahead of the 'craft to intercept any large debris.

Payload
Contains the super-computer that runs and controls all the spacecraft's systems throughout the journey. The decks in this area contain unmanned probes that will be sent out to explore regions of deep space as it approaches and reaches its target.

A Gasdynamic Mirror, seen above, is an example of a magnetic mirror based fusion propulsion system.

Project Icarus

Launched in 2009, Project Icarus is a five-year mission to make real the dream of interstellar exploration



Four propellant tanks
These fuel the reaction chamber. Once the fuel is expended, these tanks can be individually jettisoned.

Antenna
These keep the probe in contact with mission control on Earth. All data gathered is relayed back to Earth for analysis.

Reaction chamber
The chamber and surrounding structure is made out of very strong, yet light molybdenum TZM alloy that can withstand temperatures of 1,327°C (2,420°F). The hemispherical shell acts as a shock absorber to absorb the energy produced by the plasma radiated by the ignition of the fuel pellets.

By any standards, Project Icarus is a very ambitious attempt at assessing the requirements for an unmanned interstellar probe, using current and developing technology. In the process of producing technical reports on the physics, functionality, engineering and performance requirements of the 'craft, needed for different types of mission profiles, it is hoped to provide inspiration for a new generation of scientists and to boost the possibility of bringing such a scheme into reality.

The project is an update of the British Interplanetary Society's Project Daedalus that ran from 1973 to 1978. Daedalus envisaged a huge two-stage 54 million kilogram (119 million pound) nuclear fusion-powered spacecraft fuelled by deuterium helium-3.

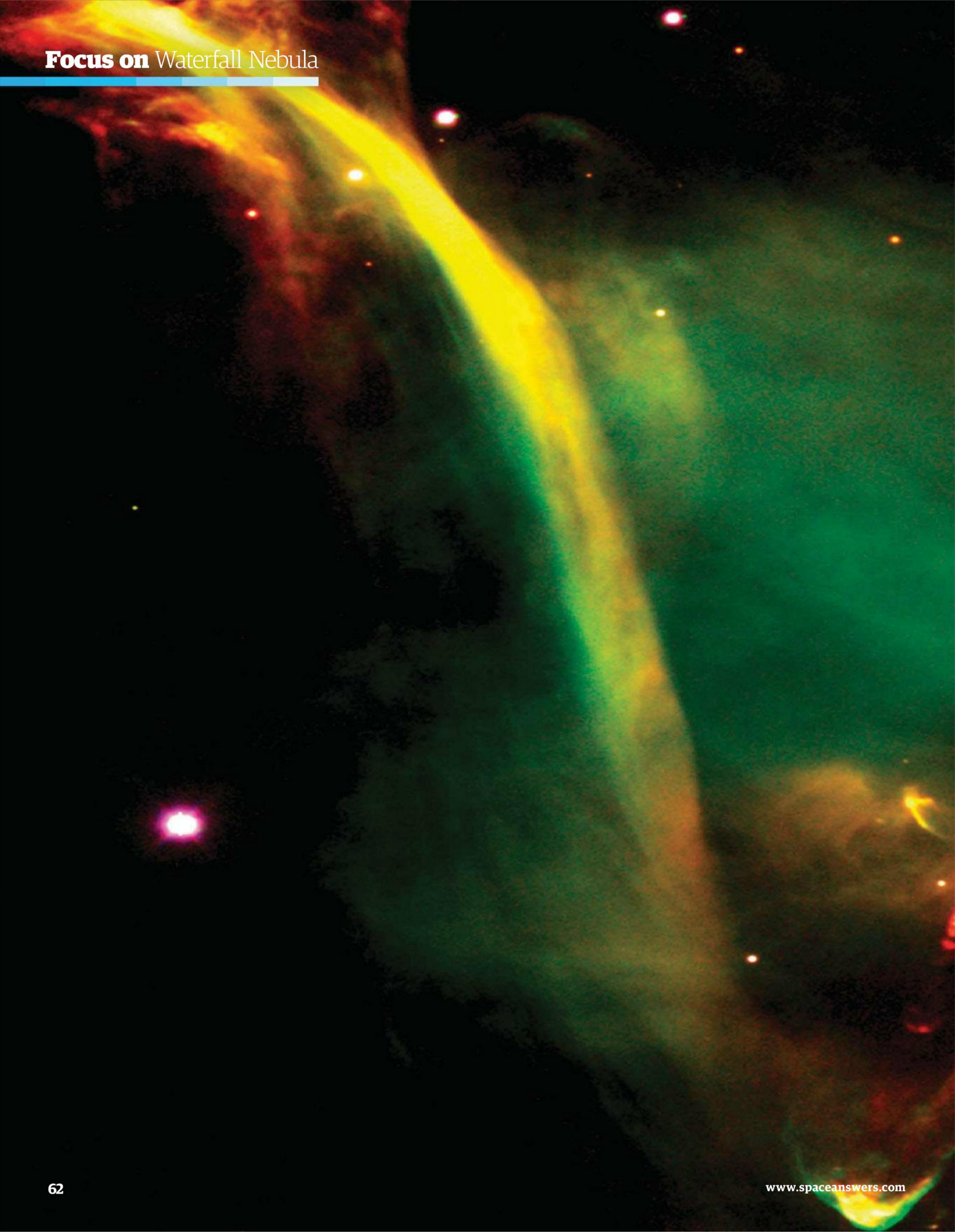
The intentions of Project Icarus are to design a similar unmanned fusion-powered space probe that can be targeted at a variety of nearby star systems, and can reach and scientifically study them within a span of 100 years. The goal is to initiate the launch of such a vehicle by 2100 at the least.

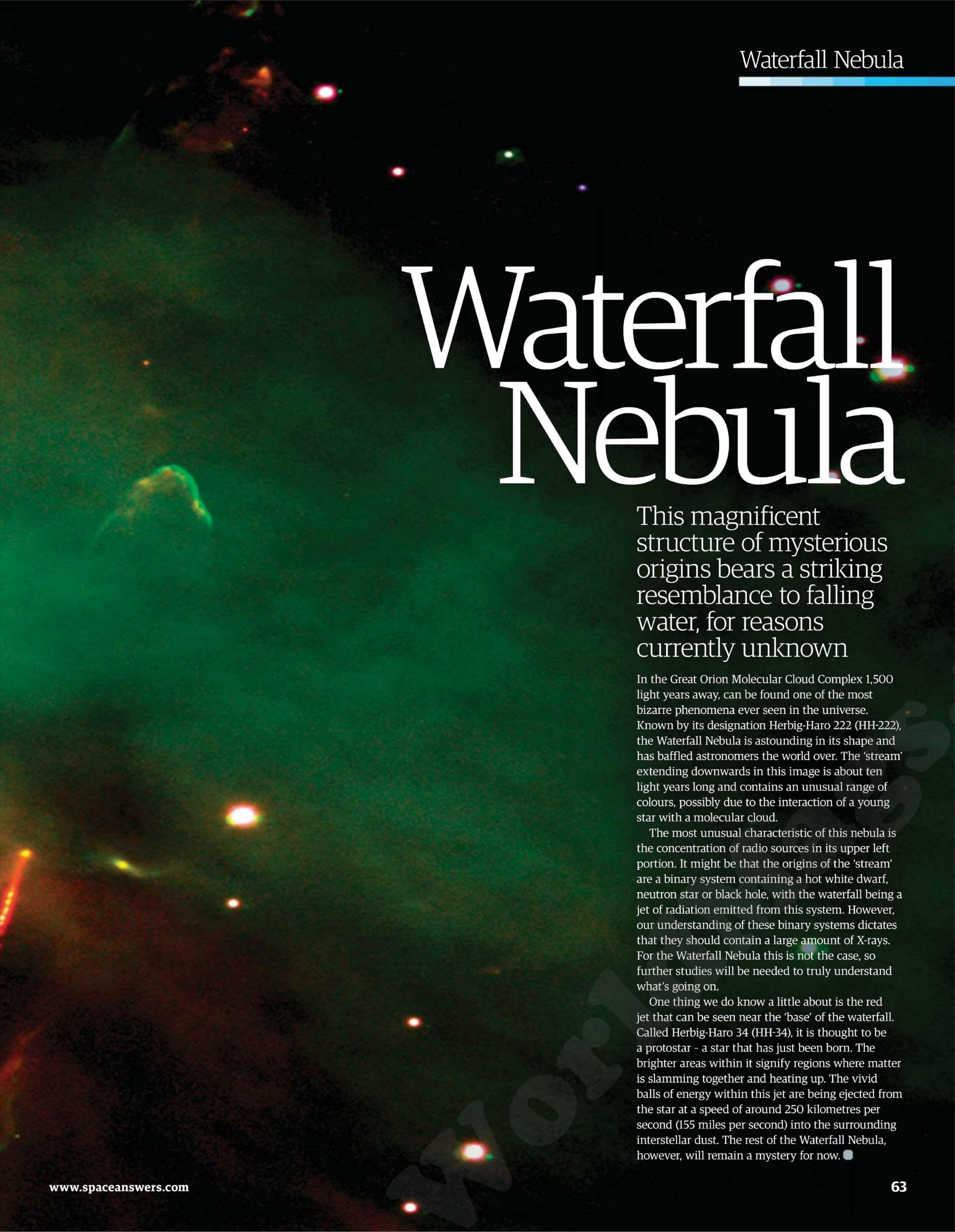
The vast scale of this project is underlined by the fact that the helium-3 fuel to power the Daedalus 'craft can only be gathered in the atmosphere of Jupiter. This would take 20 years for robot factories, held afloat by huge balloons, to mine and process the fuel into coin-sized pellets.

The 'craft would be constructed in Earth orbit or near Jupiter, and propelled by a fusion pulse propulsion engine. 250 fuel pellets per second would be injected into the engine's reaction chamber and detonated by electron beams. To provide the forward thrust, magnetic field coils channel the plasma produced out of a nozzle.

A variety of smaller 'craft based on the Daedalus proposal are being considered by Project Icarus, including the Starfinder MkI that could travel the 10,000 AU distance to the Oort cloud in 50 years and could be launched in 2050. Twenty years later, the Starfinder MkII could visit a star system 50,000 AU away in a period of 100 years. It would take until 2200 to launch anything as ambitious as the original Daedalus spacecraft.

With the increasing amount of extrasolar planets being discovered, it is an exciting possibility that Icarus-inspired 'craft could explore worlds much like our own by the end of the century.





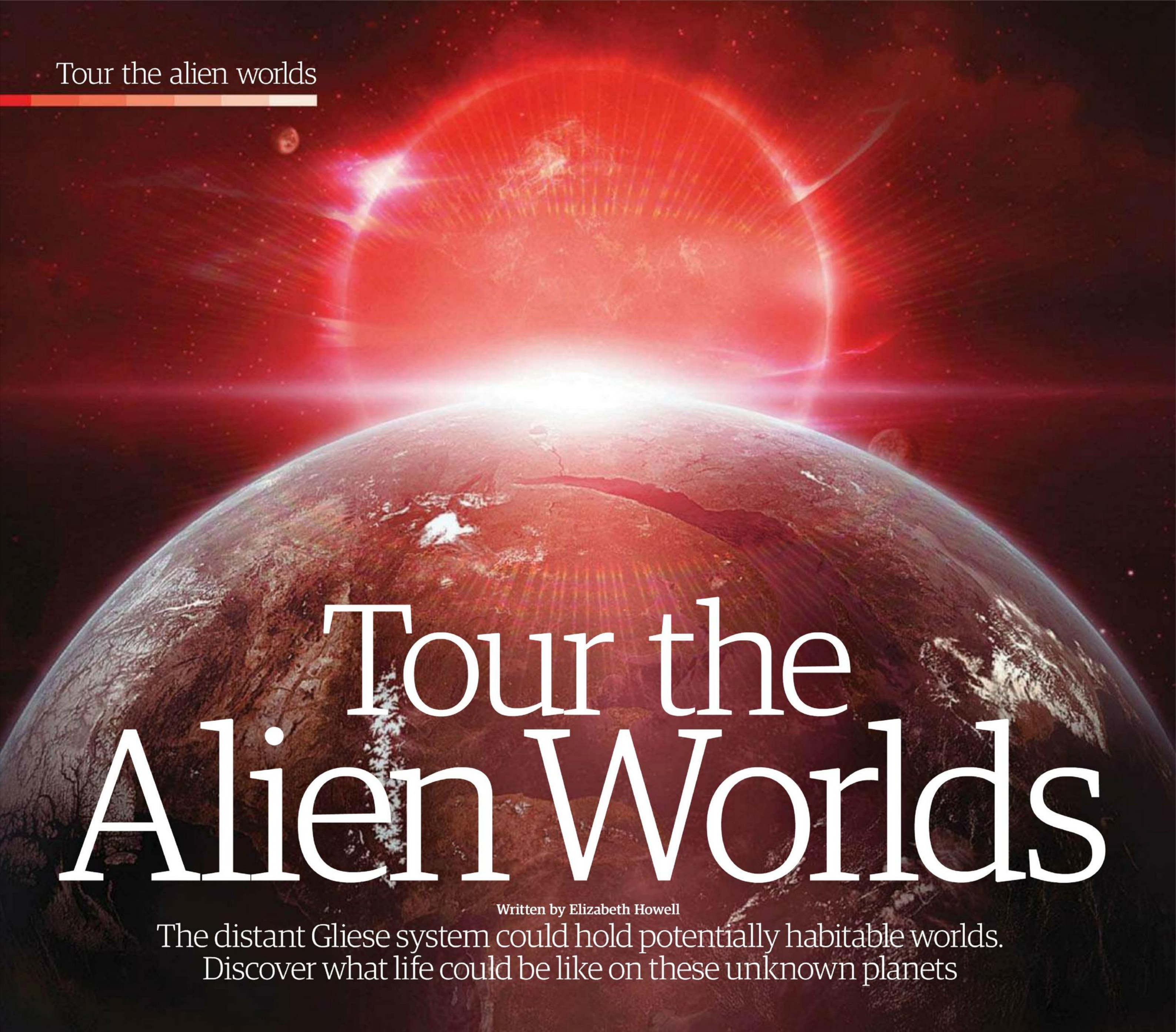
Waterfall Nebula

This magnificent structure of mysterious origins bears a striking resemblance to falling water, for reasons currently unknown

In the Great Orion Molecular Cloud Complex 1,500 light years away, can be found one of the most bizarre phenomena ever seen in the universe. Known by its designation Herbig-Haro 222 (HH-222), the Waterfall Nebula is astounding in its shape and has baffled astronomers the world over. The 'stream' extending downwards in this image is about ten light years long and contains an unusual range of colours, possibly due to the interaction of a young star with a molecular cloud.

The most unusual characteristic of this nebula is the concentration of radio sources in its upper left portion. It might be that the origins of the 'stream' are a binary system containing a hot white dwarf, neutron star or black hole, with the waterfall being a jet of radiation emitted from this system. However, our understanding of these binary systems dictates that they should contain a large amount of X-rays. For the Waterfall Nebula this is not the case, so further studies will be needed to truly understand what's going on.

One thing we do know a little about is the red jet that can be seen near the 'base' of the waterfall. Called Herbig-Haro 34 (HH-34), it is thought to be a protostar – a star that has just been born. The brighter areas within it signify regions where matter is slamming together and heating up. The vivid balls of energy within this jet are being ejected from the star at a speed of around 250 kilometres per second (155 miles per second) into the surrounding interstellar dust. The rest of the Waterfall Nebula, however, will remain a mystery for now.



Tour the Alien Worlds

Written by Elizabeth Howell

The distant Gliese system could hold potentially habitable worlds. Discover what life could be like on these unknown planets

Only 20 light years away from Earth lies a world that, if it were confirmed, looks pretty similar to our own. Gliese 581 g (as it is known by astronomers) is only three to four times the mass of Earth. It's tricky to say if it exists for sure because of the different measurement techniques used by various astronomers, but the possibilities are tantalising.

Astronomers using the WM Keck Observatory in Hawaii spotted evidence of the planet in 2010. It's thought to be a rocky planet, just like Earth, it probably has an atmosphere and, most importantly, it's in the 'Goldilocks Zone' around a star. This is the zone where temperatures are not too hot and not too cold but 'just right' to support life.

"This is a really exciting system," says Lisa Kaltenegger, an astrophysicist at Harvard University. "If it had water, it would be actually liquid on the surface. It's the first time we've been able to peer across space and detect a possible planet that would be similar to our own."

Even if 581 g turns out to be a false finding, there is even hope that another planet in the same system - 581 d - could support life, if it had a layer of carbon dioxide protecting water on its surface. This makes the entire star's solar system a fascinating target for astronomers.

Planet G of the Gliese 581 system is one of several planets orbiting the red dwarf star. Gliese 581 is a small star only 20 light years away from Earth. Because the star is a red dwarf, it gives off less heat and light than our Sun, which means its Goldilocks Zone is much closer to the star than the one in which the Earth resides in our Solar System.

Gliese 581's known planets hug the star very closely and the furthest planet from the star, Gliese 581 f, orbits at about the same distance as the planet Venus is from our Sun. (It should be emphasised that Gliese 581 f is not recognised by all astronomers yet.) The rest of Gliese 581's planets are closer to the star than Mercury's orbit from the Sun.

According to Kaltenegger, who splits her research time between Harvard and Germany's famous Max Planck Institute for Astronomy, Gliese 581 has two potential planets that lie around the habitable area. Planet G is the best candidate, if it exists, and Planet D lies just on the outer edge of the zone. But Kaltenegger says it's best not to get too excited yet. "We have great targets, but we don't know if (they) can support life," she says, adding that the next step is to find a way to use telescopes to peer closer at these planets' atmospheres.

Kaltenegger is keen to note that not everyone is in agreement about Planet G's existence. Although announced with great fanfare by NASA and related astronomers in 2010, the way the astronomers detected the planet has not been reliably replicated yet, at least as far as Kaltenegger sees it. Astronomers at the University of

> "It's the first time we've been able to peer across space and detect a possible planet that would be similar to our own"
> **Lisa Kaltenegger, astrophysicist at Harvard University**

California, Santa Cruz used 11 years of telescope observations at Keck to find Gliese 581 g, using a spectrometer that watched over its parent star. The spectrometer was used to measure the star's radial velocity, or its movement relative to Earth's line of sight. If a star has planets that are large enough and close enough, the planets tug at the star's gravity ever so slightly. With multiple planets orbiting the star, the star begins to wobble.

Planet hunters have become so sophisticated in their techniques that they can take a star's wobble and infer how many planets are orbiting it, as well as the masses of those planets.

"Keck's long-term observations of the wobble of nearby stars enabled the detection of this multi-planetary system," stated Mario Perez, a programme scientist at the Keck Observatory, in the news release concerning Planet G's discovery.

However, a team from Geneva (led by Francesco Pepe) analysed over six years of data concerning Gliese 581 using a spectrometer at La Silla Telescope in Chile.

Also in 2010, they announced at an exoplanet conference in Italy that they had not found any evidence of Gliese 581 g. That said, the precision of the instrument is not sharp enough to definitively rule Gliese 581 g out.

Subsequent teams of astronomers have been arguing back and forth for years now whether 581 g is actually there, or if the wobble detected around the star needs to have a new model made to explain it. It will take more observations of the star before anyone can say for sure what lies within that system and a definitive answer may not come for years or even decades.

The planet 581 d lies slightly further from the star than 581 g. It's also a bit larger than our world at between five and seven Earth masses. In a science paper posted on Arxiv, Kaltenegger's team calls it a "potentially habitable rocky Super-Earth".

Also, it's a little on the cold side when it comes to habitability, but some astronomers believe a thick layer of carbon dioxide in the atmosphere could shield 581 d from the cold. Of course, that's assuming the planet has an Earth-like composition, which is not a guarantee.

The theory, as Kaltenegger explains it, is carbon dioxide gets emitted from volcanoes on 581 d's surface. In the early days of the planet's formation, rain would wash the carbon dioxide out of the atmosphere so it couldn't accumulate. But as the planet cooled, that rain would turn into snow. Snow doesn't have the same power to wash carbon dioxide away, so the gas would accumulate in the atmosphere.

"It builds up in the atmosphere, increases your greenhouse effect, and warms until you have water," Kaltenegger says. This makes it easier to believe that life would exist there.

Even if planets 581 g and 581 d were vegetated, though, it would look a lot different from Earth. The cool light from Gliese 581 would barely be enough for plants to photosynthesise, so the plants would not be green like you would see here on Earth. The colour would take too much energy. Additionally, the light would look different than what we are used to on Earth, as a red dwarf mostly gives off its energy in red light.

In 2012, Australian astronomers – who are involved in the search for extraterrestrial life – trained their cosmic ears at Gliese 581. They linked together three radio telescopes in Australia in an attempt to hear radio signals coming from the system.

The astronomers didn't hear anything, but that's not to say that life is absent from the system. Gliese 581 d and 581 g are both in or within the habitable zones, and it will take many years of future study to learn more about their climatic conditions.

In the meantime, Gliese 581's system provides plenty for astronomers to study. There are up to six planets orbiting the star, each with a unique environment worth closer study.

While 581 f and 581 g are not universally accepted, there are four others that are receiving further attention from astronomers.

581 e is the closest to the star and would appear as a big Mercury if you were standing on the surface. It's about double the mass of Earth.

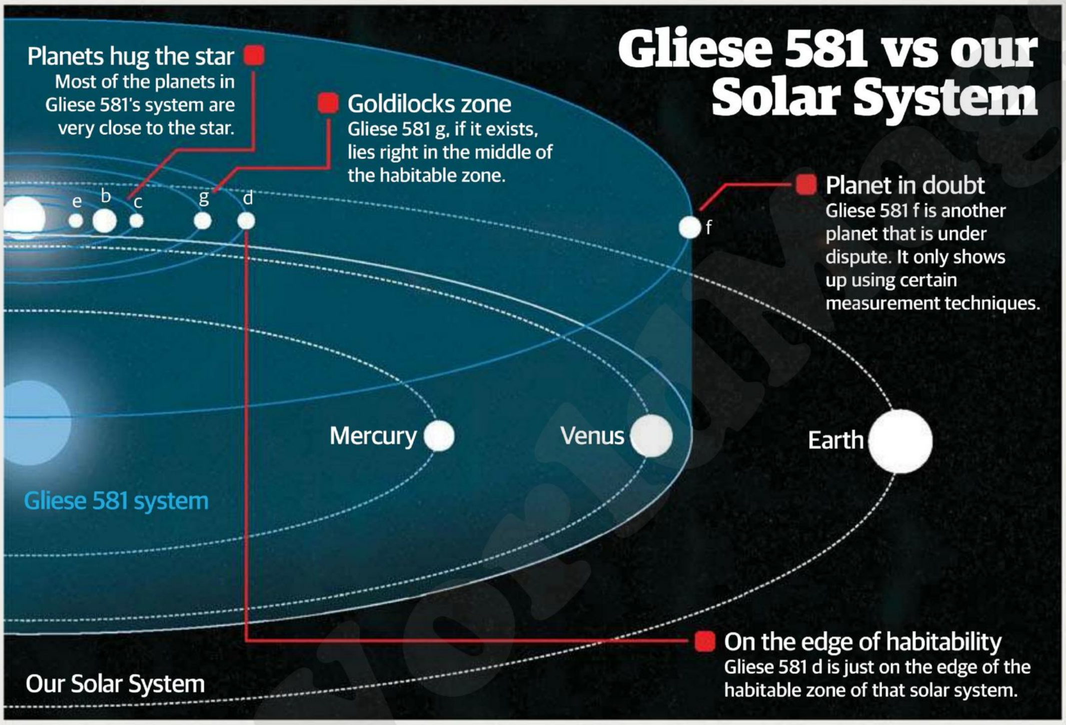
Next out is 581 b, which would be a gas planet – at 15.6 Earth masses – that is approaching the size of Jupiter.

Third in the system, and before 581 g and 581 d, is 581 c. Planet C, more than five times Earth's mass, would actually look a lot like Venus, in that any water would have evaporated from the surface and it would probably be covered in a thick atmosphere if it had any available to it.

Kaltenegger says we are just at the beginning of understanding the Gliese 581 system. "Planets are so hard to find because they look tiny near the star," she explains. "(What's) exciting is we're finding more and more planets with this simple wobble method… we can even find the small ones that don't have much mass or are not very big."

Surely as telescopic observations and computer technology continue to improve, we'll have the opportunity to spot more candidates for supporting life like Gliese 581 d or 581 g. We'll be able to more precisely predict how planets move about their stars, and also be able to infer the composition of their atmospheres.

Learning more about the way other solar systems formed brings us to a better understanding of what happened here on Earth. Gliese 581's system, even though it is 20 light years away from us, will therefore teach us more about our own home. ■



Planets hug the star Most of the planets in Gliese 581's system are very close to the star.

Goldilocks zone Gliese 581 g, if it exists, lies right in the middle of the habitable zone.

Planet in doubt Gliese 581 f is another planet that is under dispute. It only shows up using certain measurement techniques.

On the edge of habitability Gliese 581 d is just on the edge of the habitable zone of that solar system.

WorldMags

On the surface – an expert's view

We asked expert Lisa Kaltenegger to take an educated guess at what conditions might be like on the planets surrounding Gliese 581

Gliese 581 e

"The Gliese 581 system is intriguing because it hosts planets that could be like big Earths and also planets that are so different from the ones we know in our Solar System," said Kaltenegger. Gliese 581 e is estimated to have a mass about double that of Earth, and "at this mass we can speculate that it could resemble a hot super-Mercury on a three-day orbit." It is extremely close to the Gliese star and therefore likely to be very hot.

Gliese 581 b

"Without more information we can only speculate what these planets could be like - until we get a bigger telescope that can explore their atmospheres and tell us what they are like," said Kaltenegger. This is especially true for Gliese 581 b. "All of the planets in the Gliese system are heavier than Earth." The heaviest of those is Gliese 581 b at almost 16 Earth masses, which could be a "hot mini-Neptune" or a Venus-like world.

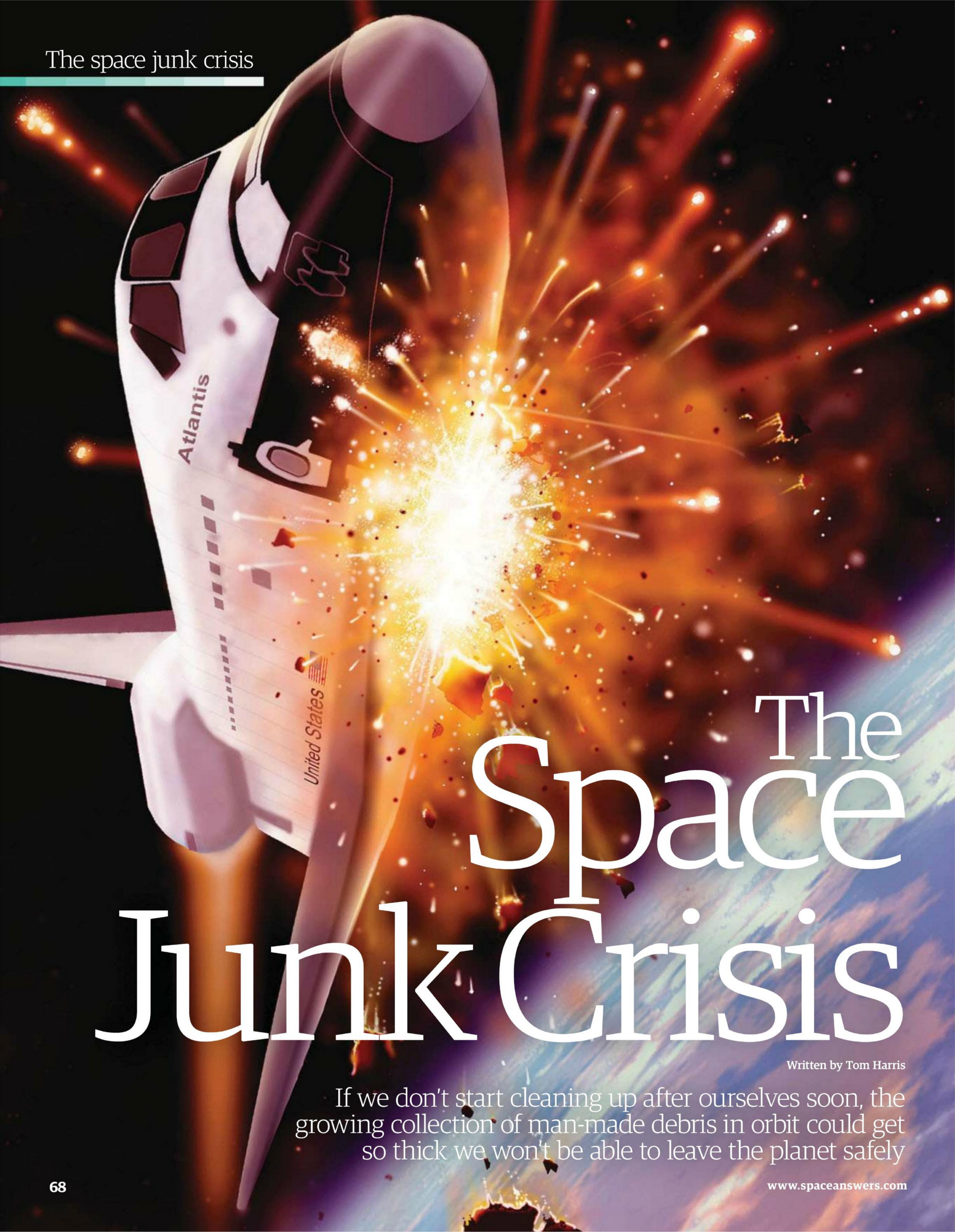
> "The Gliese 581 system is intriguing because it hosts planets that could be like big Earths"

Gliese 581 c

The "heavy super-Venus" Gliese 581 c would likely resemble the hottest planet in our Solar System, with a mass at least 5.6 times that of Earth, making it a so-called "super-Earth", although "the jury is still out on how rocky any of these planets can be." Once thought to be a prime candidate for habitability, the current train of thought is that Gliese 581 c would be inhospitable to life as we know it due to its hot environment.

Gliese 581 d

This is probably the most Earth-like of these planets, found in the system's habitable zone. "If Gliese 581 d is really a rocky planet that could have developed life," says Kaltenegger, "then such life would be used to a red sun in its sky and may have very different dark vegetation – if it developed at all. It would be a heavy, cooler, super-Earth with about double Earth's gravity, a workout for us were we ever to set foot on the surface."



The Space Junk Crisis

Written by Tom Harris

If we don't start cleaning up after ourselves soon, the growing collection of man-made debris in orbit could get so thick we won't be able to leave the planet safely

Eugene Stansbery (far left) and his team work tirelessly to track debris in Earth's orbit

Launching stuff into space is an inherently messy business. You end up leaving behind scattered rocket structures, fuel, nuts, bolts and other miscellaneous equipment. Pieces fall away, collisions turn bigger pieces into many smaller pieces, and unspent propellants cause jettisoned rocket structures to explode. In the Sixties, the US even dumped 480 million pieces of copper wire into orbit in an effort to create an artificial meteor trail that would reflect radio signals.

All of this poses a real threat to the International Space Station (ISS), active satellites and, to a far lesser extent, all of us on the ground. Even very small pieces, such as tiny chips of metal or paint, can wreak considerable damage. Space debris in low Earth orbit (LEO) typically travels at about seven to eight kilometres per second (4.3-4.9 miles per second), about seven times faster than a rifle bullet. A collision with a one-centimetre (0.4-inch) object at that speed is the equivalent of being hit by a bowling ball travelling about 480 kilometres per hour (298 miles per hour). Such an impact could single-handedly destroy a satellite.

Fortunately, most of the junk poses no physical threat to us on Earth. Atmospheric friction easily vaporises smaller debris. On average, one piece of tracked space debris dips into our atmosphere every day, and the vast majority of it never makes it to the Earth's surface. Larger pieces, such as intact rocket structures, can make it through without burning up completely, but the odds are it will end up in the ocean, which covers 71 per cent of the Earth's surface.

In the early days of space exploration, orbital debris wasn't a big concern. But once the risks of space debris became clear, agencies started to address the problem.

"NASA pioneered mitigation procedures for minimising debris," says Eugene Stansbery, program manager of the NASA Orbital Debris Program Office. "Now, many space agencies have adopted mitigation standards or requirements. There is also a set of United Nations Space Debris Mitigation Guidelines (that) deal with minimising debris during routine operations, limiting the potential for collisions by reducing the lifetime spent in crowded orbits, reducing the risk of explosion by eliminating stored energy at end-of-operational life, and limiting risk to humans on the ground from re-entering satellites."

A key strategy is to ensure upper-stage rockets end up at a lower-altitude orbit, leading them to dip into the Earth's atmosphere more quickly. Debris left at altitudes below 600 kilometres (372 miles) will burn up within about three to four years. Debris left at 800 kilometres (497 miles) may be in orbit for decades. Any debris above 1,000 kilometres (621 miles) will take a century or more to reach the atmosphere.

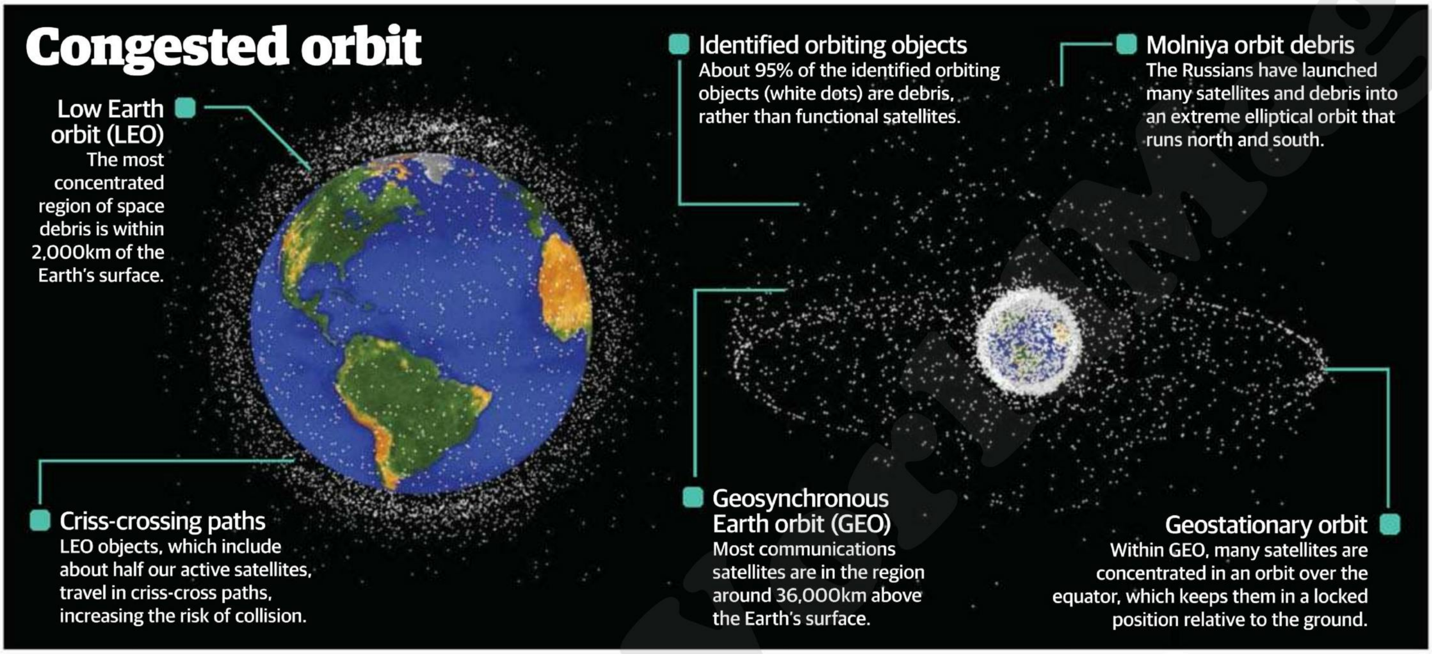
Today, Stansbery explains, all we can do is keep track of the most dangerous debris in orbit so we can stay clear of it: "In the US, the Department of Defense (DoD) operates the Space Surveillance Network (SSN), which consists of a worldwide network of radar and optical sensors, including one space-based sensor, which tracks satellites, including orbital debris. This network is controlled and tasked by the Joint Space Operations Center (JSpOC) located at Vandenberg Air Force Base, in California."

The network is equipped to observe debris in low Earth orbit (LEO) as well as geosynchronous orbit (GEO). "Normally radars are used to track low Earth orbital debris," Stansbery explains, "and optical telescopes are used for geosynchronous debris. Optical telescopes provide 'angles-only' data whereas radar typically provides an additional measure of the range to the debris. Perturbations to the orbits are also different for the two regimes. Therefore, the algorithms and software used to determine and maintain the orbits are different for the two regimes."

Keeping satellites and spacecraft safe depends on precisely charting the debris' path in relation to all the operational objects in orbit.

"A series of observations is taken on an object either by radar or by optical telescope," Stansbery says. "An initial orbit is estimated from these observations. That orbit is then propagated forward in time to predict its location when it is in view of other sensors. These sensors will look for the object and use its position to refine the orbit. Once the orbit [of the object] is sufficiently determined, sensors are

Congested orbit



Low Earth orbit (LEO)
The most concentrated region of space debris is within 2,000km of the Earth's surface.

Identified orbiting objects
About 95% of the identified orbiting objects (white dots) are debris, rather than functional satellites.

Molniya orbit debris
The Russians have launched many satellites and debris into an extreme elliptical orbit that runs north and south.

Criss-crossing paths
LEO objects, which include about half our active satellites, travel in criss-cross paths, increasing the risk of collision.

Geosynchronous Earth orbit (GEO)
Most communications satellites are in the region around 36,000km above the Earth's surface.

Geostationary orbit
Within GEO, many satellites are concentrated in an orbit over the equator, which keeps them in a locked position relative to the ground.

then routinely tasked to update the object's orbit as needed."

It's not possible to track all debris, Stansbery says: "The primary obstacle to tracking debris is the small size of the debris. Radars and optical telescopes are limited by their sensitivity. In low Earth orbit, the SSN can only detect debris bigger than five to ten centimetres (two to four inches) effective diameter. At geosynchronous altitudes, it only detects debris larger than about one metre (3.2 feet) diameter. These sizes are a small fraction of the orbital debris that can damage a typical spacecraft."

Stansbery says computers are key to avoiding collisions: "The JSpOC runs a software product that predicts close approaches between active satellites and other orbital objects. If a close approach is predicted, the JSpOC will issue an Orbital Conjunction Message (OCM), which has the locations and uncertainties in location for the conjuncting objects. An operator can then determine what actions, such as moving the satellite, are prudent."

The top priority is avoiding catastrophic collisions with manned spacecraft, such as the ISS.

"For the ISS and related spacecraft, there is a group at Johnson Space Center that receives the OCM," Stansbery says. "This group takes the orbit and orbit uncertainties and calculates a probability of collision. Based on this probability, there are flight rules that dictate what must be done when certain probability thresholds are exceeded. The action would normally be a manoeuvre given enough time. Time is needed to plan and execute a manoeuvre. During the buildup to a manoeuvre, the team monitors any additional tracking information from JSpOC and can cancel the manoeuvre if later data indicates a reduced risk."

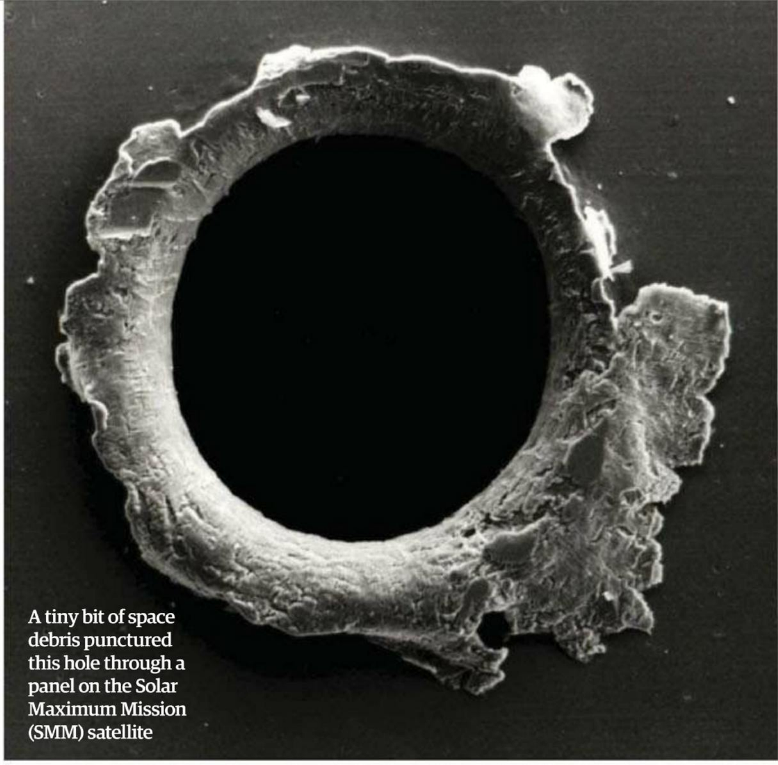
On average, the ISS has to move out of the way of tracked debris twice a year, about double the frequency of several years ago. There isn't always time to move clear of the debris.

"Sometimes, the warning of a conjunction does not come soon enough to safely plan and execute a manoeuvre," Stansbery says. "This has occasionally resulted in what is termed 'safe haven' where the ISS crew will move to their Soyuz return capsule until the conjunction has passed."

In the event of a collision, space junk trackers suddenly have a host of new debris to catalogue.

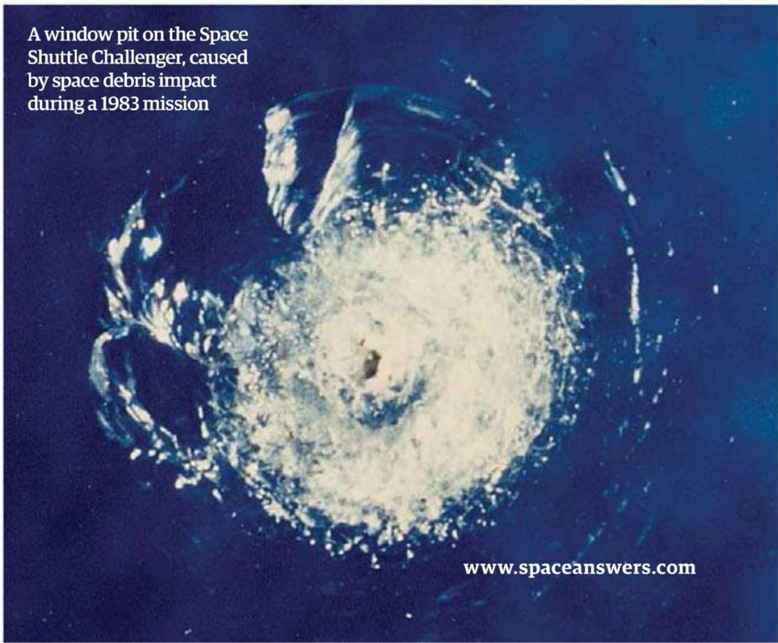
"NASA's Orbital Debris Program Office performs several tasks," Stansbery says. "First, we use a software package that takes the information on the time, location, and masses of the objects and calculates near and mid-term risk to other spacecraft, most notably, the ISS. These risk estimates tell the crew if they should take action. Then, NASA begins to collect as much data on the collision as it can in order to characterise the collision better and evaluate long-term damage to the environment."

Stansbery says the Space Surveillance Network has some upgrades on the horizon: "There are a couple of new sensors that promise improved sensitivity. DoD is planning a new 'Space Fence' phased array radar that will be able to detect and track debris as small as two centimetres (0.8 inches) effective diameter at


A tiny bit of space debris punctured this hole through a panel on the Solar Maximum Mission (SMM) satellite

A 250kg (550lb) stainless steel propellant tank from a Delta II launch vehicle that landed mostly intact near Georgetown, Texas in 1997

The 'Space Fence' mission control will track pieces of space junk that are in orbit around the Earth


A window pit on the Space Shuttle Challenger, caused by space debris impact during a 1983 mission

The AN/FPS-85 radar in Florida is one of 29 sensors in the Space Surveillance Network (SSN)

The Kiernan Reentry Measurement Site (KREMS), a US facility on Kwajalein Atoll in the Pacific Ocean, includes four one-of-a-kind radar systems that play integral roles in the Space Surveillance Network (SSN)

space station altitudes. The DoD is also testing the Space Surveillance Telescope (SST) which will improve sensitivity for geosynchronous orbits."

Up until recently, the biggest source of individual debris pieces was rocket explosions. In its early days, NASA routinely let upper-stage rockets enter orbit with unspent fuel, leading them to blow up, scattering bits of shrapnel into orbit. In the past six years, two unfortunate events put satellite pieces at the top of the debris list.

First, in 2007, China tested its anti-satellite capabilities by destroying one of its own weather satellites with a missile. The explosion created more than 150,000 pieces of space debris, making it the worst space junk event in history. Then, in 2009, an accidental collision between a defunct Russian military satellite and a US communications satellite added more than 2,000 additional pieces.

These collisions illustrated a sobering, very real danger: the threat of a chain reaction of collisions. NASA astrophysicist Donald Kessler predicted this scenario, dubbed the Kessler Syndrome, in 1978. He saw that at the rate we were going, we would reach a point where the volume of space junk in orbit would be large enough that collisions would yield smaller pieces of debris faster than the rate all the junk could burn up in the atmosphere.

The crux of the problem is that a single bump between two pieces of debris can create thousands of smaller pieces of debris, which can then collide with other debris, creating thousands of new pieces. Destroying just one large satellite could double, or possibly triple the amount of debris in low Earth orbit.

Today, Kessler has a clear vision of the course we're on: "Unless some country or organisation significantly increases the rate that objects are being placed into the various regions of Earth orbit, the rate of debris growth is fairly predictable: one can expect it to slowly increase in regions of Earth orbit below 2,000 kilometres [1,240 miles] (LEO), regardless of what actions are taken to try to prevent that growth, as a result of random collisions involving large, intact objects."

Kessler predicts technology will have to evolve to keep up with the increased junk: "Over the next 100 years, we can expect to see a slow increase in the rate of spacecraft failures due to an increasing number of hypervelocity impacts of small debris fragments resulting from these collisions. Spacecraft operators will slowly realise they need to add shielding to critical components, increasing the weight of their spacecraft, even though the added weight will be undesirable, although it will be manageable for many decades."

The rate of major collisions will increase too, he says: "During this time, we can expect about one catastrophic, debris-producing collision every ten years; there would be little possibility that we'd notice any 'collisional cascading' until perhaps near the end of the century, when the frequency of catastrophic collisions would become more frequent, depending on the success of previous actions to slow the growth in the debris population that are already in place (eg minimising the possibility of explosions in orbit and requiring new spacecraft to be out of orbit within 25 years at the end of their operational life)."

Because we're beyond the point where more conscientious launches will eventually solve the problem, we'll end up locking ourselves in with a wall of rubbish if we don't start cleaning up after ourselves.

Kessler sees an immediate need for action: "Without the beginning of more aggressive actions within the next few decades to reduce the current population of large intact objects in LEO, the growth in the debris will accelerate, and not stop increasing for hundreds, if not thousands, of years, making LEO too hazardous an environment for any spacecraft to operate for any significant length of time before it will become another source of debris."

Things might also progress more quickly, Kessler says: "This scenario could become much worse if some entity were to place a large constellation, consisting of thousands

Collisions and near misses

February 2009

The first man-made satellite collision

A 560kg satellite operated by the US company Iridium was just one month away from retirement when it smashed into a 950kg Russian Kosmos military satellite. The collision added more than 2,000 pieces of debris to Earth orbit.

January 1997

It's raining junk

An Oklahoma woman on a late-night stroll saw a streak of light in the sky and then felt something brush her shoulder – a piece of metal from a US Delta II rocket launched in 1996. The same night, a 260kg steel fuel tank narrowly missed an occupied farmhouse.

January 1978

Radioactive landing

When the Soviets lost control of their surveillance satellite Kosmos 954, its erratic orbit took it back to Earth, spreading debris over Canada's Northwest Territories. The Canadian and US military initiated a $124,000km^2$ search for radioactive material from the satellite.

June 2011

Buzzing the International Space Station

With only 15 hours notice, the ISS crew didn't have time to move clear of a piece of junk hurtling towards them. The 1 in 360 chance of impact sent the crew to their Soyuz space capsules, ready to undock and escape to Earth, but thankfully, the object missed by 260m.

> "The primary obstacle to tracking debris is the small size of the debris. Radars and optical telescopes are limited by their sensitivity"
>
> **Eugene Stansbery, program manager of the NASA Orbital Debris Program Office**

of satellites in LEO, as was proposed for our 'Star Wars' defence programme in the Eighties. Hopefully, we are wise enough today to avoid that. There is also a possibility that the natural orbital decay rate of satellites in LEO will decrease if we should experience the kind of low sunspot activity as was observed in the late 17th Century, thinning the upper atmosphere and increasing the need to physically remove more satellites from orbit."

The first order of business is planning ahead with new objects we put into orbit going forward.

"There are two other popular regions of Earth orbital space," Kessler says. "Mid Earth orbit (MEO), where GPS satellites are located, and geosynchronous orbit (GEO), where satellite TV transmitters are located. Both will suffer the same fate (as LEO), but over a longer time period. We could avoid this fate in GEO if there is widespread agreement to place objects in an inclined orbit that significantly reduces collision velocities between uncontrolled satellites. If adopted, such an orbit also has the advantage of saving station-keeping fuel for spacecraft operators. Objects in both LEO and MEO must be on paths that cover large areas of the Earth's surface in order to meet their operational goals. Consequently, the only solution to the orbital debris issue in those regions is to not leave objects in orbit after they've fulfilled their operational roles. A small, pre-planned, propulsion capability is sufficient to remove objects from LEO, and many future payloads and upper-stage rockets are planned to have this capability."

The big question now, however, is how to deal with all the debris that's already in orbit.

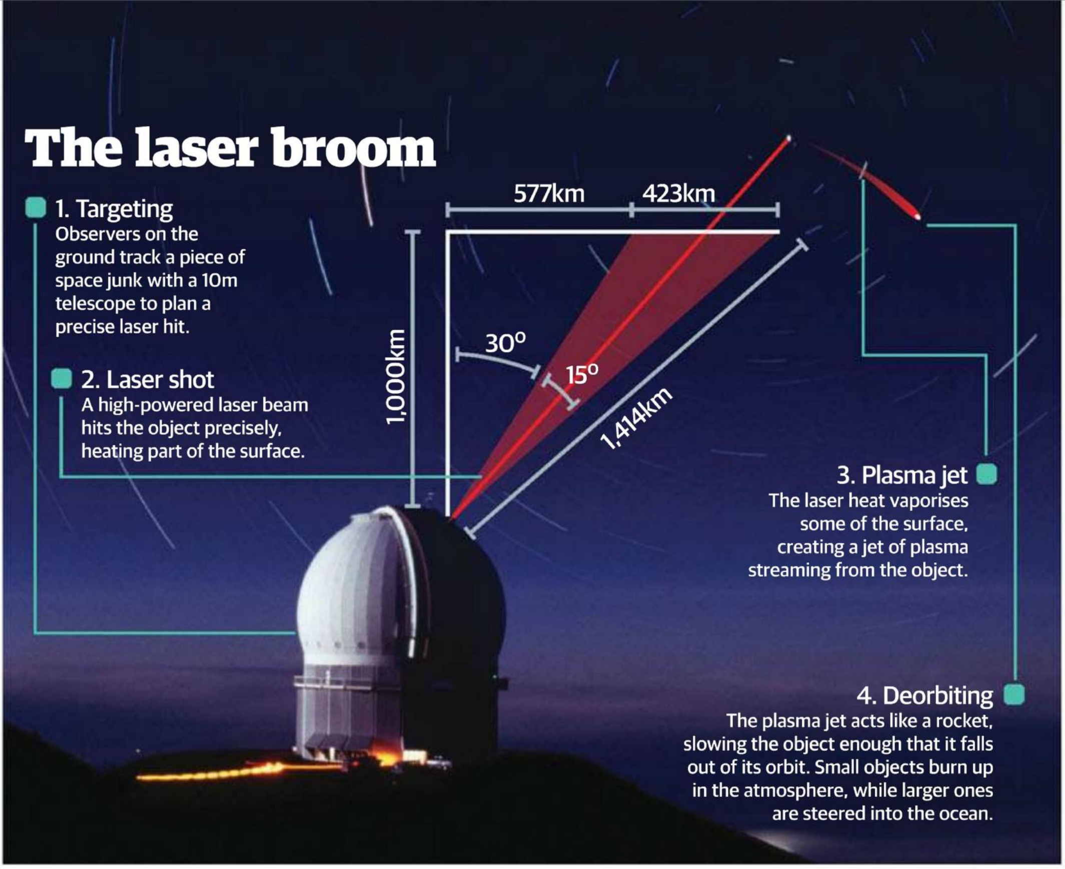
"There have been a number of proposals for removing existing debris," Stansbery says. "At present no system that is both technologically mature and economically feasible has been proposed. However, the United States and other countries are pursuing research and development of technologies and techniques to remove in-orbit debris."

Stansbery explains the challenge is twofold: "It is really a combination of physics and economics. The classical way of removing large satellites from orbit is to rendezvous with the object, matching velocities so that the encounter doesn't result in a collision. Then you attach to the satellite and move it to either a graveyard orbit or cause the satellite to re-enter the Earth's atmosphere without undue hazard to people on the ground. This is a very energy-intensive scenario. Also, economically, removing one large satellite can be very expensive when launch costs and operations are considered. The removal of one, or a handful, of large satellites, does not significantly reduce the risk. Many, many satellites need to be removed via a long-term, sustained effort."

In the face of these obstacles, scientists have been looking into alternative measures. One option is to target debris with a ground-based laser. The laser would heat the debris just enough to produce a small plasma jet, which would act as a rocket to slow the debris down so that it falls into Earth atmosphere.

Boeing is exploring a rocket design that would release about ten tons of inert cryogenic gas, such as xenon or krypton, into a debris-heavy areas. In the seconds before it dissipated, the cloud of gas would theoretically slow the debris enough for it to fall out of orbit. That's right: the solution to cleaning up space junk might just be launching more junk into space. ■

The laser broom



1. Targeting
Observers on the ground track a piece of space junk with a 10m telescope to plan a precise laser hit.

2. Laser shot
A high-powered laser beam hits the object precisely, heating part of the surface.

3. Plasma jet
The laser heat vaporises some of the surface, creating a jet of plasma streaming from the object.

4. Deorbiting
The plasma jet acts like a rocket, slowing the object enough that it falls out of its orbit. Small objects burn up in the atmosphere, while larger ones are steered into the ocean.

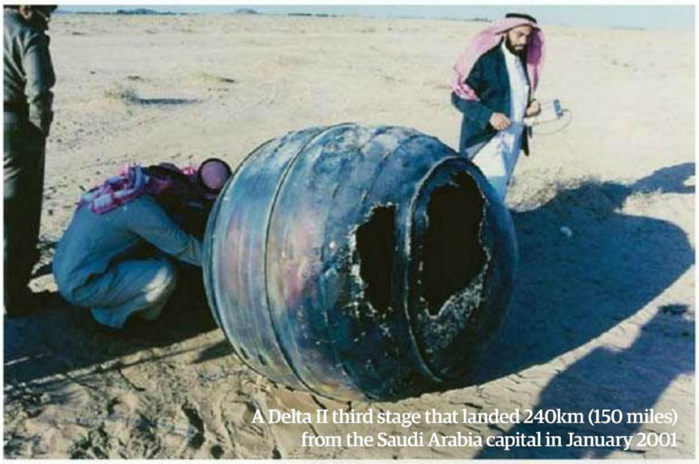
> "One option being looked into by scientists in a bid to remove space debris from orbit is to target the junk with a ground-based laser"

Lost in space

Tool bag
Astronaut Heide Stefanyshyn-Piper lost a 14kg tool bag on an ISS spacewalk in November 2008, which could be seen in orbit from Earth.

Glove
Astronaut Ed White lost a glove on the Gemini 4 mission in 1965 during the first-ever American spacewalk. It stayed in orbit for a month.

Spatula
Space Shuttle astronaut Piers Sellers lost a spatula on a spacewalk in July 2006 while spreading material on the shuttle's heat shields.



A Delta II third stage that landed 240km (150 miles) from the Saudi Arabia capital in January 2001

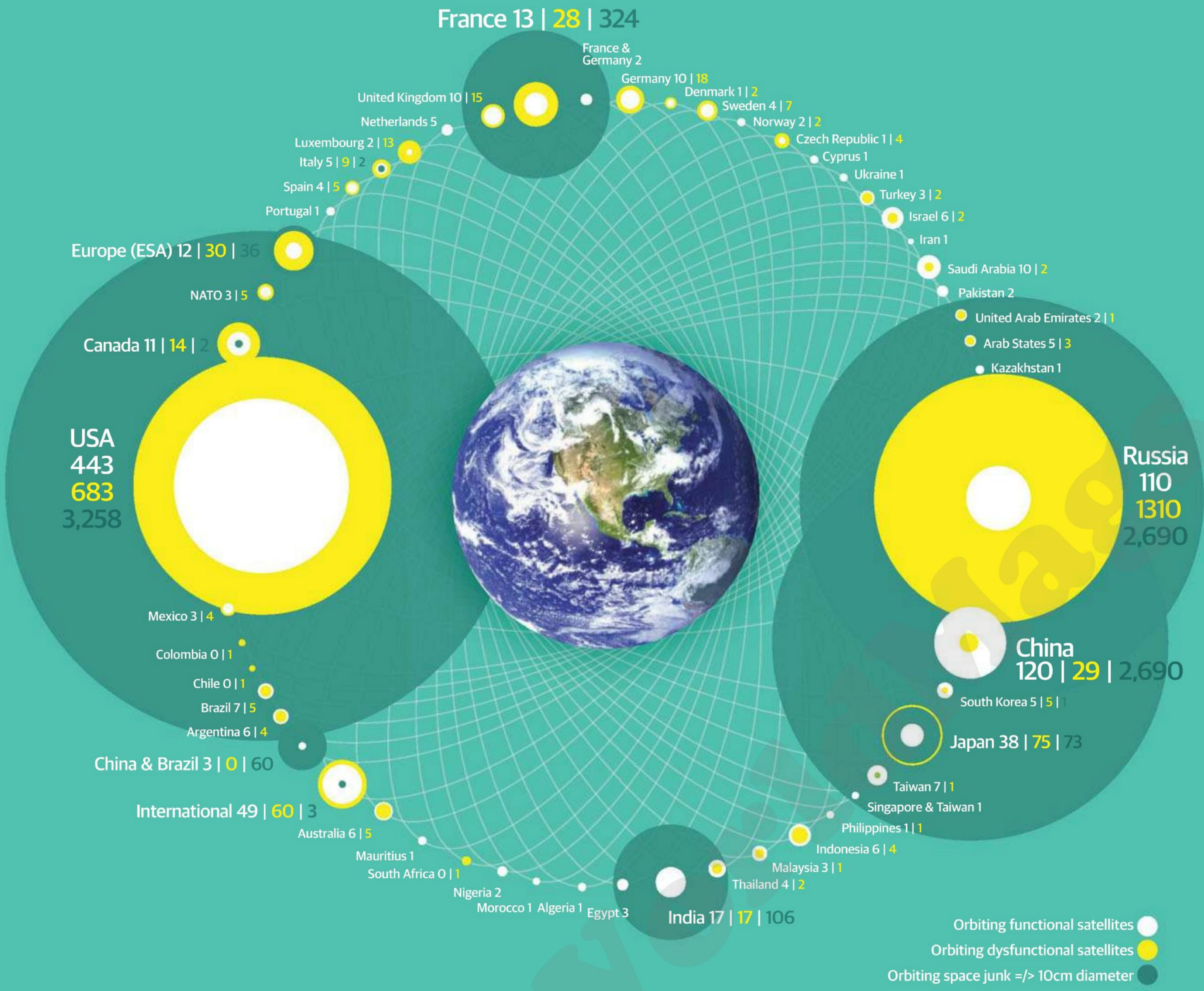
The orbital scrapyard

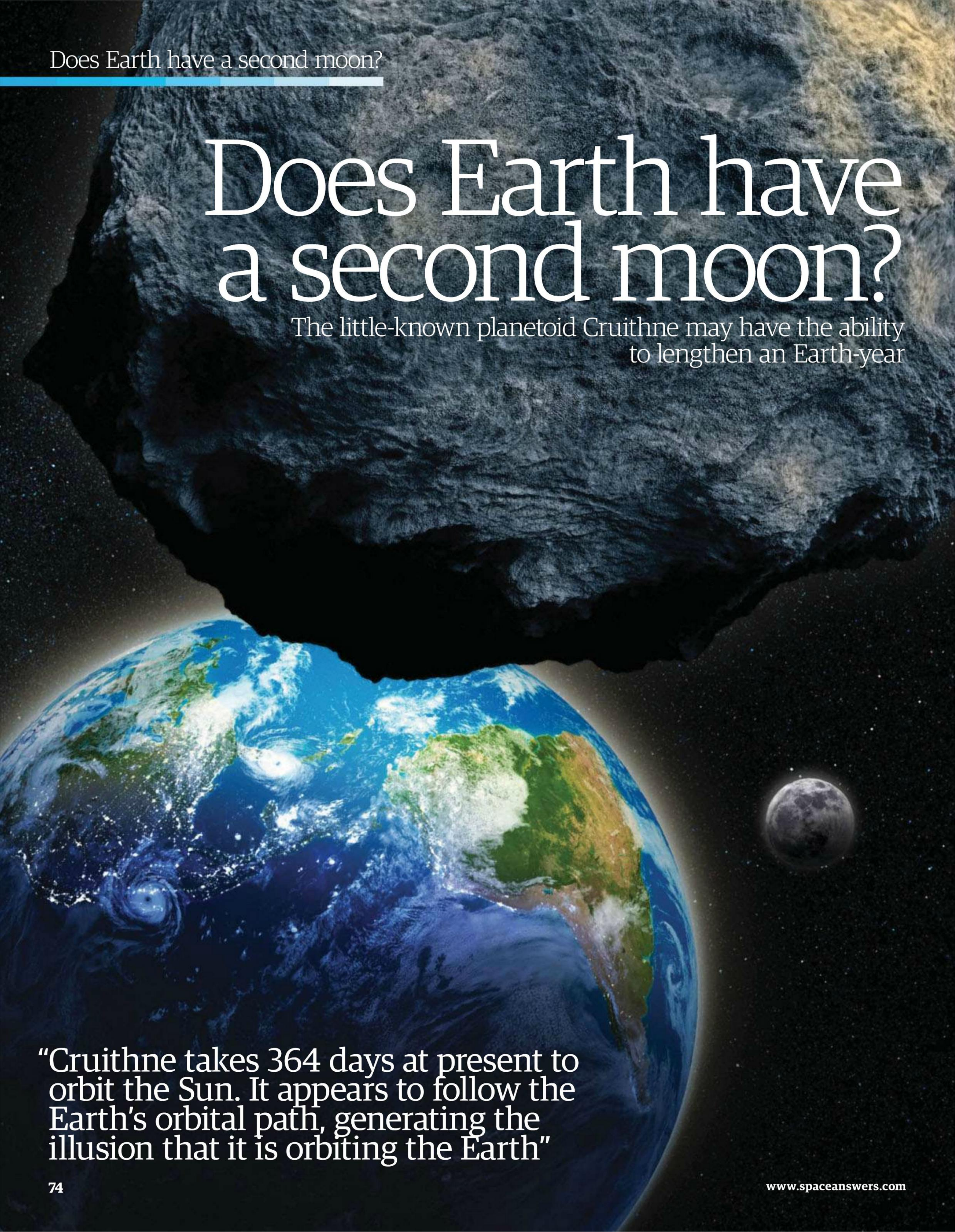
Unsurprisingly, the three countries with the biggest space programmes – the United States, Russia (including the former Soviet Union) and China – are also responsible for contributing the greatest amount of space debris, as well as the greatest number of active satellites.

Russia has contributed the most mass, claiming about 53 per cent of the whole. It also leads in percentage of individual pieces of debris with 37.8 per cent, but the United States isn't too far behind with 30.1 per cent. Collectively, the rest of the world has only contributed 9.7 per cent of the total objects and 24 per cent of the total mass.

When China intentionally destroyed a satellite in a 2007 missile test, it shot to the top in ratio of individual pieces of space debris to launched satellites and spacecraft. While China has only contributed around four per cent of the total space junk mass, it's contributed 22.4 per cent of the individual pieces of debris.

Thankfully, Russia, the United States and China are all looking into measures to track, minimise and remove debris from Earth's orbit in the future.





Does Earth have a second moon?

The little-known planetoid Cruithne may have the ability to lengthen an Earth-year

"Cruithne takes 364 days at present to orbit the Sun. It appears to follow the Earth's orbital path, generating the illusion that it is orbiting the Earth"

When Cruithne, a small planetoid, was initially discovered on 10 October 1986, there was a brief moment when astronomers thought they were looking at Earth's second moon. It was a mysterious object passing by Earth in what appeared to be a stable orbit. It was difficult to see, due to its passing of 30 times the distance of the Moon (12 million kilometres or 7.5 million miles), but its behaviour and size excited all aware of its existence.

However, unfortunately its true nature – while impressive and intriguing – was not as initially thought. Closer inspection revealed that Cruithne was a quasi-satellite, not a moon, and, far from orbiting around Earth, it in fact orbited around the Sun on an elliptical orbit and a unique horseshoe orbit relative to the planet.

Despite Earth's second satellite not being the long searched for 'second moon', it is still an incredibly interesting stellar object. Cruithne is approximately five kilometres (3.1 miles) in diameter, has a unique horseshoe-shaped orbit when viewed from Earth and is synchronised with Earth's orbit acutely (see 'Influence on Earth's gravity' boxout). Indeed, as Cruithne takes 364 days at present to orbit the Sun, it appears to follow the Earth's orbital path – and vice versa – generating the illusion that it is orbiting the Earth.

In reality, though, it is not orbiting Earth, as aforementioned, and while close in total orbit time around the Sun, Cruithne has a much higher orbital eccentricity than Earth, a factor that causes its speed and position to vary. This, in partnership with it taking one day less to orbit the Sun than Earth, means that each year the Earth falls a little further behind the planetoid on its orbit. As such, from the perspective of Earth, Cruithne is slowly becoming more distant currently at its closest passing point.

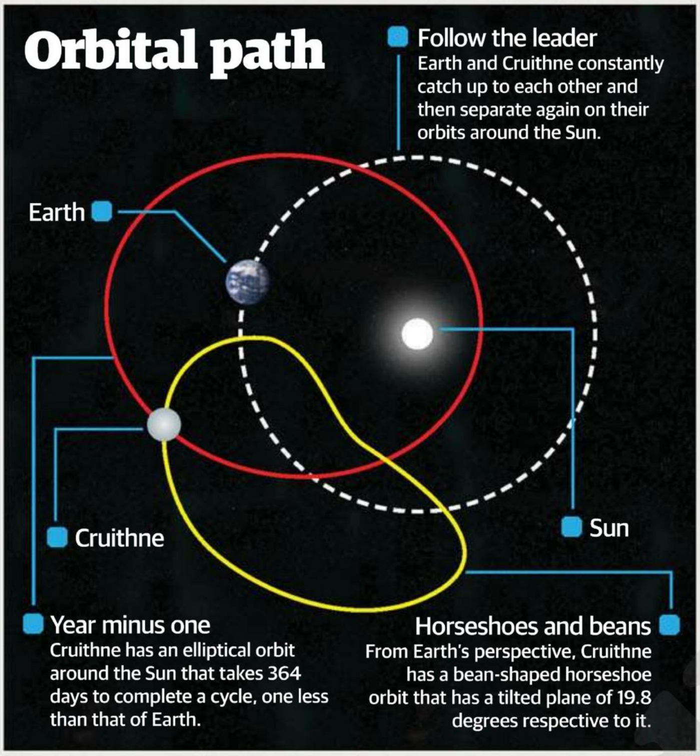
Interestingly, eventually Earth will fall so far behind Cruithne that it will begin to catch it up from behind, leading to a series of close approaches where the satellite and Earth will gravitationally exchange orbital energy. This will alter Cruithne's orbit by over 500,000 kilometres (310,000 miles) and Earth's by 1.3 centimetres (0.51 inches), the latter effect extending its orbit around the Sun to over 365 days.

Luckily, however, this gravitational exchange is not due next until July 2292, meaning that at least for the moment, calendars around the world can rest safe and unaltered.

Since Cruithne was founded additional resonant, near-Earth objects have been discovered to pass the planet. These include a near-Earth Aten-class asteroid – Aten asteroids are a group of near-Earth asteroids with high orbital eccentricity – an Apollo-class near-Earth asteroid, which is interesting as aside from it being an Earth-crosser asteroid its rate of rotation is increasing perpetually, and the first-ever Earth Trojan asteroid to be discovered, entitled 2010 TK$_7$. This Earth Trojan is expected to make a close approach to Earth on 5 December 2012.

Interestingly, Cruithne's perceived horseshoe orbit from Earth is not unique, with other planets experiencing similar phenomena. Saturn's inner satellites Janus and Epimetheus, for example, not only also have horseshoe-shaped orbits, but are in fact co-orbital too, sharing and swapping each other's orbit periodically (once every four years). Unlike Cruithne's co-orbital motion, though, for both these have greatly simplified motion. However, as both are technically inner satellites of the planet – unlike Cruithne, which orbits the Sun – they have a greater right to be named moons.

Orbital path



Follow the leader
Earth and Cruithne constantly catch up to each other and then separate again on their orbits around the Sun.

Year minus one
Cruithne has an elliptical orbit around the Sun that takes 364 days to complete a cycle, one less than that of Earth.

Horseshoes and beans
From Earth's perspective, Cruithne has a bean-shaped horseshoe orbit that has a tilted plane of 19.8 degrees respective to it.

Influence on Earth's gravity

Cruithne may have the ability to affect gravity on Earth via a process called orbital resonance. This is the process in which two orbiting bodies exert a regular, periodic gravitational influence on each other. This is commonly due to their close proximity to each other, and entails a type of push and pull effect on each body. This behaviour typically manifests an unstable interaction in which the two bodies affect each other's momentum and orbit until the resonance is no longer effective. However, there are cases where the resonance is stable, with consequent interactions correcting the previous interaction, as crudely demonstrated by Earth and Cruithne's one-to-one orbital resonance, with each gravitational exchange of energy increasing and decreasing their orbital periods in sequence. What is most common, however, when a mass-heavy object shares an orbital resonance with a mass-light body, is that the former ejects the latter from the area of influence, breaking the resonance.

Searching for Cruithne

1846 - Frédéric Petit

In 1846, French astronomer Frédéric Petit claimed he had discovered a second moon in an elliptical orbit around the Earth. Unfortunately, his claim was soon dismissed by the establishment.

1898 - Georg Waltemath

German scientist Waltemath announced he had discovered a system of moons orbiting Earth. One moon was supposedly 1 million km (620,000 miles) from Earth. The scientific community could not find the moons, however, and he was discredited.

1918 - Walter Gorn Old

Astrologer Walter Gorn Old claimed to have found Waltemath's moon and named it Lilith. He said it was a 'dark moon' and therefore invisible most of the time. Observation efforts since have failed to find Lilith and it is discredited.

1969 - John Bargby

American scientist Bargby claimed to have discovered a series of ten small natural objects orbiting Earth between 1966 and 1969. However, the objects could not be found upon additional observations.

2011 - Erik Asphaug

In 2011, Erick Asphaug and Martin Jutzi proposed a model that suggested a second moon did once exist orbiting the Earth, however, impacted into the Moon long ago and now does not exist.

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Greatest Achievements

Written by Jonathan O'Callaghan

From the Moon landings to the Mars Science Laboratory, discover the triumphs of the world's greatest space agency

For over five decades NASA has been at the forefront of space science and exploration, launching hundreds of missions to further our understanding of Earth, the Solar System and beyond. Whittling down its multitude of accomplishments to just a handful of great achievements is no easy task, but we've chosen the ten missions and programmes that not only returned groundbreaking scientific data and images, but also those that inspired further missions and provided the framework for additional endeavours that would ensure NASA remained top of the pile. Read on to find out the missions that advanced our means of space science and exploration forever. ●

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Sophie Allan

National Space Academy Education Officer

■ Sophie studied Astrophysics at university. She has a special interest in astrobiology and planetary science.

Megan Whewell

Education Team Presenter

■ Megan has a first-class Master's degree in Astrophysics and Science Communication and specialises in the topic of star formation.

Josh Barker

Education Team Presenter

■ Having achieved a Master's degree in Physics and Astrophysics, Josh continues to pursue his interests in space at the National Space Centre.

Gemma Lavender

Science journalist

■ Gemma holds a degree in Astrophysics and has worked as a science journalist for three years. She was recently elected as a fellow of the Royal Astronomical Society.

Jonathan O'Callaghan

Senior Staff Writer

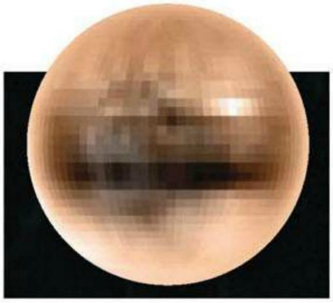
■ Jonathan read Physics and Astrophysics before becoming a writer on our sister publication **How It Works**, where he specialised in space science and exploration.

ASTRONOMY

Why can telescopes see distant galaxies in detail, but closer objects like Pluto look fuzzy?

Chris Howlett

When you look at the images of distant galaxies in all of their glory and compare them with the fuzzy greyish blob that is Pluto, you might wonder if the resolution of your telescope, or even that of the Hubble Space Telescope, is poorer when it comes to looking at planets. Obviously, a telescope won't just change its resolution depending on what object it looks at – there's a much simpler explanation and it's all down to the size of an object. Clearly galaxies are much bigger than puny Pluto and, while they are much further away, their size means that getting a high resolution is easy for a telescope, while getting the same level of detail for a tiny light-reflecting object is that much more difficult. At least without getting a much closer look. **GL**



Smaller and dimmer planets will appear in less detail in your telescope

SOLAR SYSTEM

Why is the Moon called the Moon?

Carl Puttnam

The Earth's only natural satellite has been mankind's constant nighttime companion. Over the course of human history we have been obsessed with this celestial object, noticing periodic changes in its appearance. In fact, even the original Latin word for month (mensis) was derived from the Greek name for the Moon, mene. It was the only moon we knew of until 1609 when Galileo turned his telescope towards Jupiter and spotted that it had at least four natural satellites, or moons. And to distinguish them from our own, they were each given their own names. Since then, new satellites are given new names, but the original, special satellite orbiting the Earth is the only one that we call the Moon. **SA**

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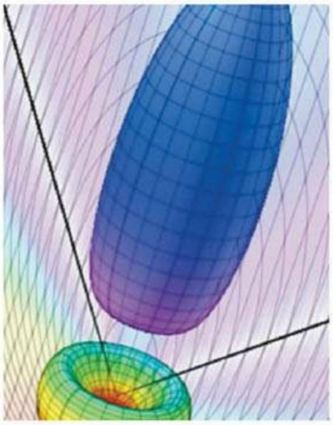
DEEP SPACE

What is a tachyon?

Adam Bennett

A tachyon, or tachyonic particle, is generally a make-believe particle that moves faster than the speed of light. While particles that gain energy react by moving quickly, tachyons do the opposite and are imagined to gain speed when they lose energy and slow down when they take in energy. As a result, the slowest that a tachyon can move is at the speed of light. Because most physicists believe that particles travelling at the speed of light cannot exist as they would violate our known laws of physics, all arguments for their existence are theoretical. No compelling evidence to support their existence has yet been found. **GL**



A visualisation of a Tachyon approaching light speed

ASTRONOMY

What existed before the Big Bang?

Michelle Pugh

The Big Bang is certainly a heavily supported theory when it comes to the creation of the universe. According to this theory, the universe was once a swelteringly hot and dense place to be before expanding rapidly and cooling, converting energy into various particles including protons, neutrons and electrons. Protons and neutrons are believed to have been made within a few minutes after the Big Bang and thousands of years later, electrons combined with them to create neutral atoms. The first element to be produced was hydrogen along with traces of helium and lithium. Gigantic clouds of these very first elements were believed to have combined through gravity to create the very first stars and galaxies and heavier elements were then made within stars or during the explosion of supernovae. According to measurements and observations of the universe today, it is believed that the Big Bang occurred around 13.8 billion years ago and since astronomers suspect that nothing existed (not even time!) before the Big Bang, 13.8 billion years is the believed age of the universe.

While it is generally thought that nothing existed before the Big Bang, some scientists favour the 'cyclic model' theory which states that the universe goes through a cycle which begins with a Big Bang and ends in a big crunch. In this case, a big crunch existed before the Big Bang. **GL**

SPACE EXPLORATION

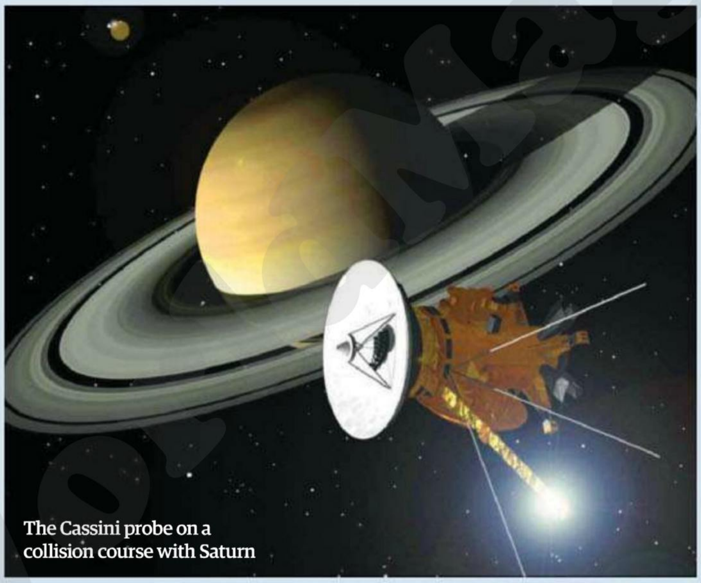
Why will Cassini impact Saturn in 2017?

Richard West

If you read our article on the Cassini spacecraft in issue 5 you may recall that, at the end, we said it was going to be purposefully sent crashing into Saturn in 2017 to prevent the contamination of nearby moons. But, why are they doing this? Why don't they fire the probe out of the Solar System and carry on gathering data?

The main reason is that, by 2017, Cassini will not have enough fuel to maintain its orbit around Saturn or to reach the required speed to escape Saturn's orbit, let alone the Solar System. Although small, there's a chance it would be pulled back into the Saturnian system and impact one of the moons. If we plan to one day explore the surface of these moons, such a collision would contaminate said moon and possibly give us incorrect data in a future mission.

Another reason to send Cassini into Saturn's atmosphere is that it will be a good opportunity to get data from the atmosphere that no probe has got before. We'll be able to study Saturn's cloud tops up close and take readings as the probe enters the atmosphere, something that probably won't be repeated for many decades. **JOC**



The Cassini probe on a collision course with Saturn

SPACE EXPLORATION

Who built the first space station?

Steve Williamson

The first-ever manned outpost to orbit the Earth was Salyut 1, launched by the Soviet Union on 19 April 1971. The station was small compared to the modern-day ISS, measuring just 20 metres (65 feet) in length and four metres (13 feet) wide. In its 175 days in space, of which only 24 saw the station manned, Salyut 1 completed 2,929 orbits of Earth and travelled a total distance of over 118 million kilometres (73 million miles) before re-entering and burning up in the Earth's atmosphere. Only one crew ever successfully docked and visited the station, the three-man crew of Soyuz 11, although they sadly lost their lives on their return to Earth and became the only astronauts to ever lose their lives in space.

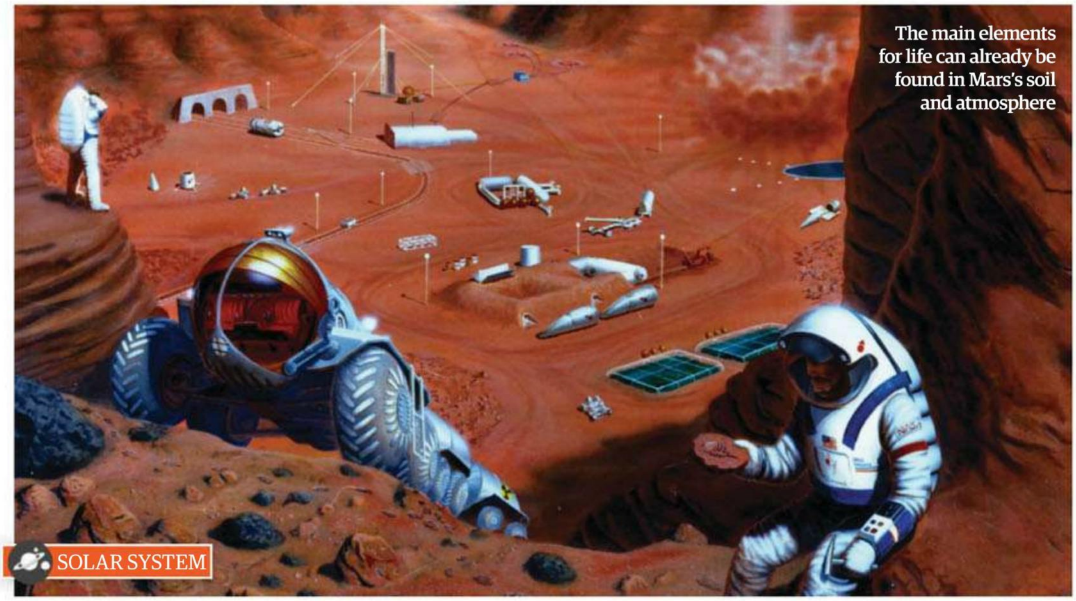
Salyut 1 was succeeded by eight more Soviet-built space stations, culminating in the construction of the Mir space station that began in 1986, with NASA's Skylab sandwiched in-between in 1973. Mir retained the record for the longest-orbiting man-made space station until being surpassed by the ISS in 2010. **JOC**

DEEP SPACE

Can a spacecraft orbit a black hole?

Tom Cuthbury

The key to orbiting any object is speed. Think about the Earth orbiting the Sun. We do not fall into our star because we are orbiting at a very high speed. However, if the Earth were to orbit any faster, our trajectory would send us away from the Sun, or at least certainly into a less circular orbit. Any slower and we would succumb to the gravitational pull of our star and fall in towards it. The same principals apply for orbiting black holes. Too slow and you will spiral in to the black hole due to the immense gravitational pull. Too fast and you will overshoot it flying off into the distance. Even at intermediate speeds, orbits around black holes would be more complicated, leading to a rosetta orbit that resembles the petals of a flower. If you are lucky and get the speed just right, you could enter into a stable, almost circular orbit, but even small changes in your speed would upset the delicate balance and knock you off course - potentially towards a high gravity end! **SA**



The main elements for life can already be found in Mars's soil and atmosphere

SOLAR SYSTEM

Could we terraform Mars?

Janine Bruce

If there was a planet that scientists would try to terraform, Mars would win hands down. Why? Because it is the most Earth-like of all of the planets in our Solar System and, according to experts, there was once a time that this rocky world was very much like how our planet appears today, with a thicker atmosphere and an abundance of water. Of course, this has all changed, with Mars being a seemingly barren place with a thin atmosphere, no geological activity and no substantial magnetic field.

Unfortunately, while the Red Planet is argued to be the easiest planet in our Solar System to turn into another habitable world, it is still a pretty difficult thing to do. Terraforming Mars would require three very important changes - building up its atmosphere, keeping it warm and keeping the atmosphere from being ripped from it and lost to outer space. So, in short, and in practice, terraforming Mars is impossible, but that doesn't mean that some scientists haven't thought about it.

Some scientists argue that the main elements for life can already be found in the soil and atmosphere of Mars, with many also believing that there are large amounts of water ice existing below the Martian surface, on the south pole and on the north pole where it is mixed with frozen carbon dioxide (dry ice). However, with the need to import ammonia and hydrogen among other elements and compounds, it would indeed be a very difficult task to terraform Mars in the near future. **GL**

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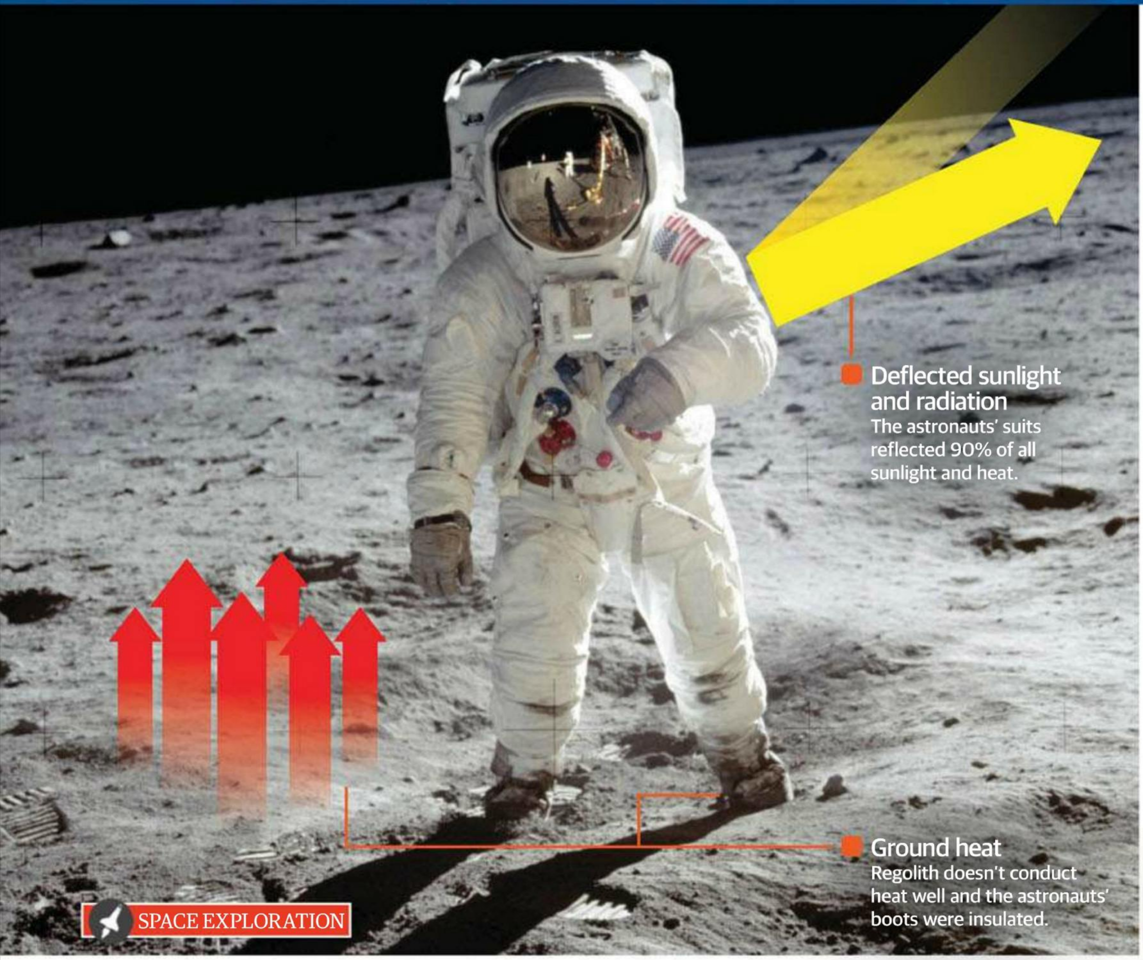

Deflected sunlight and radiation
The astronauts' suits reflected 90% of all sunlight and heat.
Ground heat
Regolith doesn't conduct heat well and the astronauts' boots were insulated.

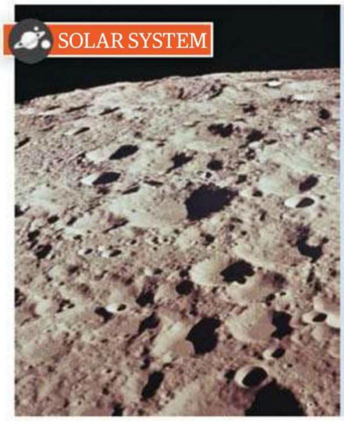
SPACE EXPLORATION

How did lunar astronauts survive changing temperature?

Scott James

Over the course of a full lunar day and night, the temperature on the Moon can vary wildly, from around +200 to -200 degrees Celsius (+392 to -328 degrees Fahrenheit), so it's natural to wonder how lunar astronauts survived this huge temperature variation. The first thing to know is that all trips on to the Moon's surface were carefully planned for lunar dawn, to ensure the surface hadn't had time to heat up fully to its daytime temperature. It is also important to think about how heat can be transferred to astronauts on the lunar surface.

There are three ways heat can transfer and only two are possible on the Moon. The first is radiation, both directly from the Sun and from the Sun's reflection on the surface. The astronauts' spacesuits were designed to reflect almost 90% of the light that reaches it, so very little heat would have transferred to the astronauts. The second is by conduction from the direct contact their feet had with the surface. This is also an ineffective process as regolith on the lunar surface doesn't conduct heat well and the astronauts' boots were insulated, slowing down conduction even further. This shows that even though huge temperature variations occur on the Moon, lunar astronauts were never actually exposed to them. **MW**



SOLAR SYSTEM

Could an asteroid hit a particular site on the Moon?

Dr Paul Bartels

First of all, the chances of anything hitting another body in the Solar System are incredibly small due to space being so mind-blowingly big. Not much information is collected about potential impacts with the Moon, making our calculation a little trickier. So, instead, we will consider an object hitting somewhere on Earth. Your house for example.

Asteroid 2011AG5, for example, has a 0.00181% chance of hitting the Earth, and the probability of it hitting a specific location on Earth is roughly 1 in 200 billion! That means you are almost 15,000 times more likely to win the lottery. So don't panic just yet! **JB**

Quick-fire questions

@spaceanswers

What's the smallest planet we know of?
Mercury is the smallest planet in the Solar System with a diameter of just under 4,900km (3,000 miles).

Who was the first woman in space?
Russian cosmonaut Valentina Vladimirovna Tereshkova travelled into space aboard Vostok 6 on 16 June 1963.

How many rocket launch sites are there around the world?
There are currently approximately 24 active rocket launch sites around the world.

How many planets have ring systems?
The gas giants Jupiter, Saturn, Uranus and Neptune.

How much does the Moon's orbit around Earth change?
Pulled into an elliptical orbit by the Sun, the Moon's angular speed and apparent size (to us here on Earth!) changes and, as a result, the Moon looks as if it is moving towards or away from us.

Would a human be able to breathe in space?
Space is what is known as a vacuum – there are no particles to make up air for us to breathe.

What's the difference between a star and a planet?
A star is a hot, luminous sphere of plasma that can reach incredibly high temperatures, whereas a planet is a much smaller, cooler sphere of rock or gas.

How many stars can you see at night?
With no light pollution on a clear moonless night, you will be able to see between 2,000 and 2,500 stars in one go provided you have 20/20 vision.

Quick-fire questions

@spaceanswers

Do all planets have molten cores?
Only if the planet has sufficient spin and a distinct core, mantle and crust as well as being big enough to retain heat within its core during formation.

What is the furthest telescope from Earth?
NASA's Wilkinson Microwave Anisotropy Probe (WMAP) and ESA's Herschel and Planck Observatories are 1.5 million km (930,000 miles) away.

What is a harvest Moon?
The big, reddish, full Moon we see closest to the autumnal equinox.

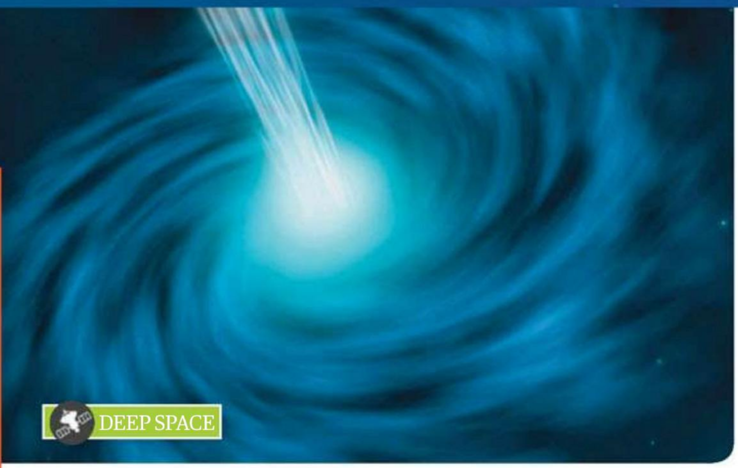
What's the difference between a missile and a rocket?
A missile has an inbuilt guiding system that gets it to its destination, whereas a rocket will go to wherever it is pointed.

Are rockets launched near the poles?
Rockets are usually launched closer to the equator.

What's the average size of a star?
Our Sun is an average star. It has a diameter of 1.4 million km (870,000 miles).

Why can we see the Moon during the daytime?
The Moon's surface is highly reflective of the Sun's light and with its brightness and size is hard to 'wash out' in the daytime sky.

What is infrared light?
Electromagnetic radiation which has a wavelength longer than visible light but shorter than radio waves. Its heating effects can be found emanating from galaxies, stars, Earth, the Sun and even us.

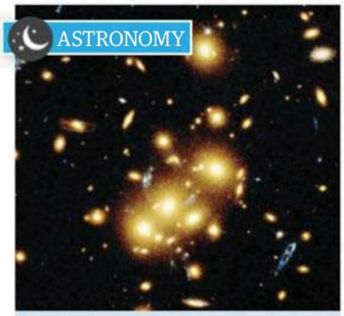


DEEP SPACE

Could a white hole lie on the other side of a black hole?

Amanda Morgan

The idea of a white hole as the reverse of a black hole is a hypothetical one. While black holes will suck anything from light to matter into its clutches, the white hole is theorised to be a region of space-time that cannot be entered from the outside, but from which matter and light can escape – presumably spitting out that same light and matter that got sucked into the black hole in the first place. The idea of a black hole having an exit into another universe has caused the idea of a wormhole to be dreamt up; a passage between both black and white holes. However, since the very existence of a white hole violates the second law of thermodynamics, chances of a reverse black hole are very slim. Further to this, when a star collapses into a black hole, no wormhole is produced and even if one was formed it would be unstable and fly apart. The idea that a black hole is a portal to another world, to another dimension or even to the other side of the universe is only really one that you're likely to find in science fiction – these exotic, high-gravity objects are really a path to death and destruction rather than anywhere fancy. **GL**



ASTRONOMY

What is driving the expansion of the universe?

Marjorie Allworth

The way in which galaxies and galaxy clusters are moving steadily apart tells us that the universe is expanding. Astronomers believe this is caused by hypothetical dark energy. All scientists know about this energy is that it makes up roughly 70% of the universe, while dark matter takes up around 25% and objects like us, the Earth and everything else takes up 5%. Originally theorists thought that the expansion of the universe was slowing but scientists studying supernovae found that its expansion is in fact accelerating. **GL**

DEEP SPACE

What would happen if you poked someone with a light year-long stick?

Robert Arthur

Let's imagine that we sent someone a light year away and then poked them with an equally long stick. Would they feel the poke before they saw us push the stick, thus receiving information faster than the speed of light? The answer is no. When you push one end of the stick, a compression wave moves down it (like a spring) at a fraction of the speed of light.

Instead, once they saw you push the stick after a year, they'd feel the poke quite a few years later. This, of course, assumes that our stick is not infinitely rigid. Our current understanding of physics is that, no matter how tightly you pack something, you cannot push atoms that close together.

But, if the stick were infinitely rigid, it would also be infinitely massive and would more than likely disintegrate as the energy between the atoms would be so great that they would escape the confines of the object. **JOC**

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SOLAR SYSTEM

What would happen if the Moon moved closer to Earth?

Sonia Vegas

The Earth's spin on its axis keeps water more or less balanced on all sides of the planet through what is known as a centrifugal force. The gravitational force of the Moon disrupts this balance, pulling a tidal bulge of water with it as it orbits our planet and as the Earth rotates, it too causes a tidal bulge on the opposite side. It is these bulges that are defined as high tide, whereas other areas are low tide. Now, moving the Moon closer to the Earth will increase the gravitational exertion of our satellite on to our planet. If our satellite were slightly closer, the tidal bulge would grow. Low tides would be lower and high tides would be higher and any low-lying coastline would be flooded. If the Moon got much closer, say 20 times closer, it would exert a greater gravitational force 400 times than what we are used to. A mighty tidal bulge would be created, hitting the land and causing great flooding, with cities such as London and New York disappearing under water. When the Moon moves on, however, the flooding subsides and the water will retreat. **GL**

SPACE EXPLORATION

How do you steer a space probe?

Richard Badger

Spacecraft are steered by utilising the laws of momentum. When probes are launched out of Earth's atmosphere they are usually travelling about 32,200km/h (25,000mph), enough to break free of Earth's gravity. If they are travelling to a deep space location they will probably use a gravitational assist manoeuvre from another planet to gain the necessary velocity to reach their destination. By giving it enough forward momentum, the probe can be sent in the direction of the celestial object it intends to reach. As space is a vacuum it maintains its forward momentum and can travel at an almost constant speed.

While travelling through space, probes are oriented by firing retro rockets. By firing a rocket at an angle, a spacecraft can be spun in a particular direction to look at a certain object, while still travelling in its intended forward direction. For example, the Cassini spacecraft is currently orbiting Saturn, so it uses its retro rockets to maintain its orbit and also to point itself in the right direction to snap images of Saturn's moons. **JOC**

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STARGAZER

GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

In this issue…

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See the five most famous stars

Discover how to locate and view the five most famous stars in the sky, and you don't even need a telescope

There's a reason we consider our most celebrated performers to be 'stars'. Both brilliant and beautiful, the real stars have been revered since the dawn of humanity, often worshipped as avatars of the gods, or admired as tranquil windows to heaven. But there are celebrities in the sky, too.

Some of the stars in the night sky have become so well known that they pervade popular culture, whether by their value for navigation, or their sheer brightness in the sky, and you can admire many of them without a telescope. Join us as we take a look at five of the biggest highlights of the night sky. From the fabulous red supergiant Betelgeuse, which can be found in the Orion constellation, to the brightest star in the sky, Sirius, which is situated in the Canis Major constellation; these are the stars among the stars. Get out there and track them down. ■

Be sure to hunt out these stars next time you get the telescope out

Jargon Buster

Variability

Some stars vary considerably in apparent brightness. Others only slightly. This is most commonly due to physical properties of the star. In some cases, more than one physical process creates a strange variability, but often the period can be determined by measuring the star's brightness each night for a long time.

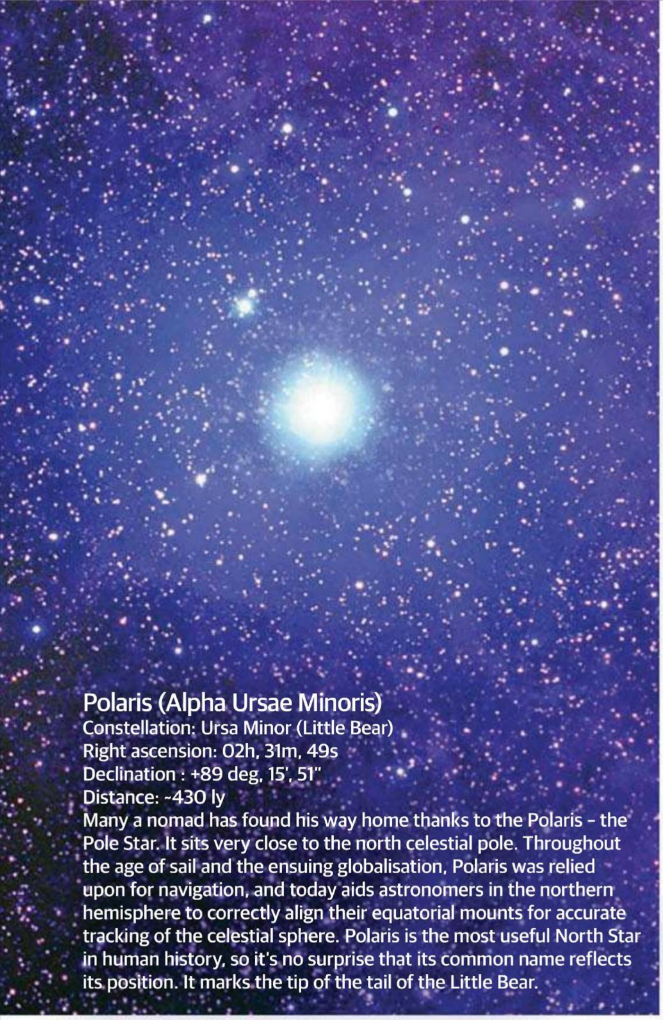
Apparition

For any given object in the night sky, the annual window in which it's visible is known as the apparition. For latitude sufficiently far from the equator, there are objects that have no apparition, but are always visible. For everything else, there is a date at which it begins to appear and a date after which it can no longer be seen in the evening.

Precession

Precession causes different stars to assume the roles of the pole stars. As the Earth spins, it wobbles slowly like a spinning top. The axis running from pole to pole also rotates, a complete cycle taking about 26,000 years. During this time the Sun's position at the equinoxes drifts westward through the zodiacal constellations.

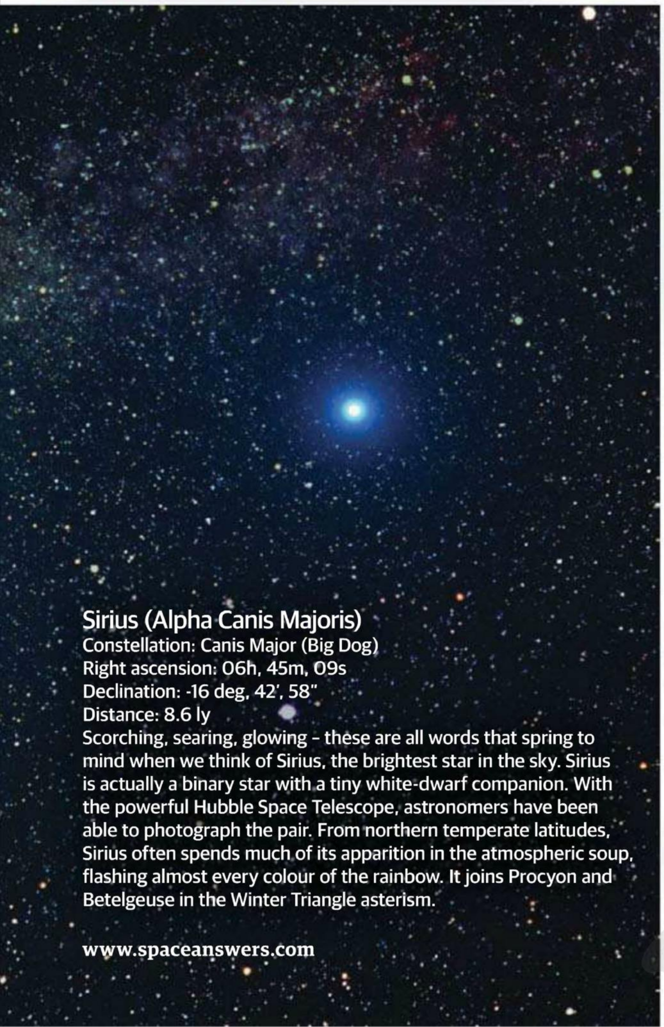
See the five most famous stars



Polaris (Alpha Ursae Minoris)

Constellation: Ursa Minor (Little Bear)
Right ascension: 02h, 31m, 49s
Declination : +89 deg, 15', 51"
Distance: ~430 ly

Many a nomad has found his way home thanks to the Polaris – the Pole Star. It sits very close to the north celestial pole. Throughout the age of sail and the ensuing globalisation, Polaris was relied upon for navigation, and today aids astronomers in the northern hemisphere to correctly align their equatorial mounts for accurate tracking of the celestial sphere. Polaris is the most useful North Star in human history, so it's no surprise that its common name reflects its position. It marks the tip of the tail of the Little Bear.



Sirius (Alpha Canis Majoris)

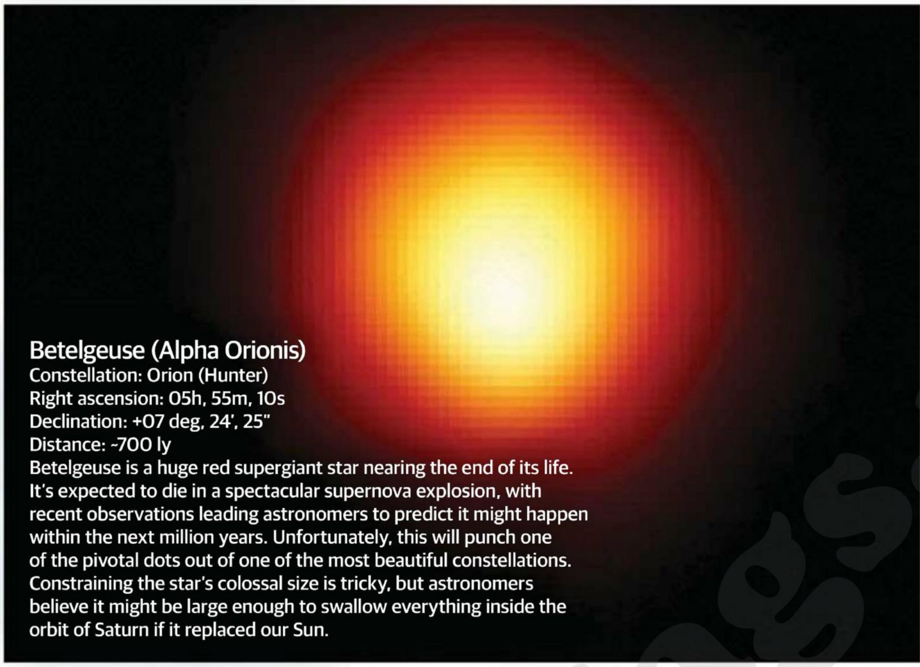
Constellation: Canis Major (Big Dog)
Right ascension: 06h, 45m, 09s
Declination: -16 deg, 42', 58"
Distance: 8.6 ly

Scorching, searing, glowing – these are all words that spring to mind when we think of Sirius, the brightest star in the sky. Sirius is actually a binary star with a tiny white-dwarf companion. With the powerful Hubble Space Telescope, astronomers have been able to photograph the pair. From northern temperate latitudes, Sirius often spends much of its apparition in the atmospheric soup, flashing almost every colour of the rainbow. It joins Procyon and Betelgeuse in the Winter Triangle asterism.

Vega (Alpha Lyrae)

Constellation: Lyra (Harp)
Right ascension: 18h, 36m, 56s
Declination: +38 deg, 47', 01"
Distance: 25 ly

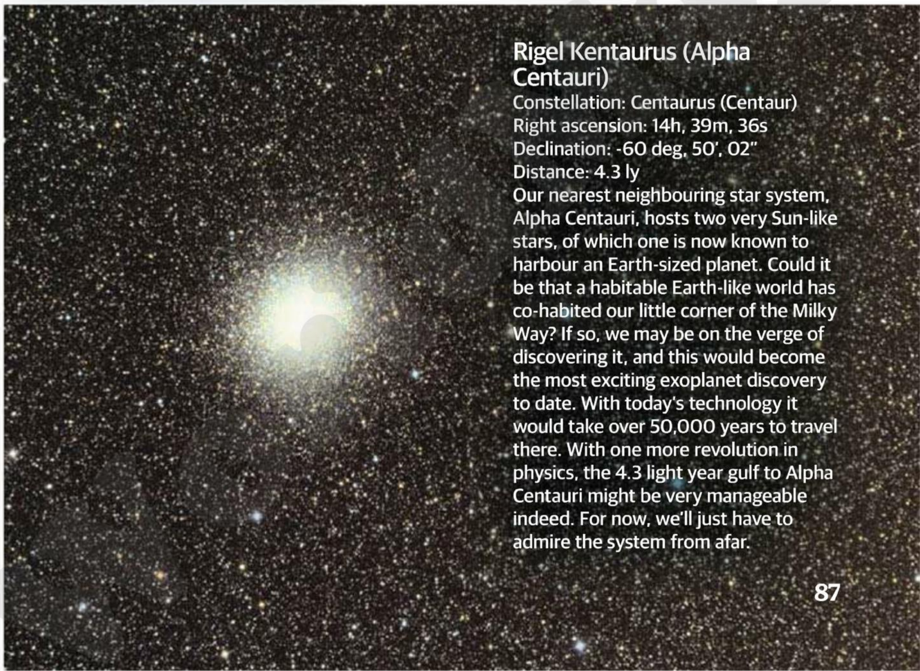
The fifth brightest star in the sky is of great importance to astronomers. Not just because it was the first star other than the Sun to be photographed; but because it was chosen as the benchmark by which astronomers would judge the brightness of all other objects in the night sky. This honour was originally granted to Polaris, but eventually Vega replaced it. This was because Vega was discovered to be an incredibly stable star, in terms of variability, whereas Polaris was found to change brightness and could not be relied upon. Astronomers now use a more accurate reference, but Vega remains very significant to modern astronomy.



Betelgeuse (Alpha Orionis)

Constellation: Orion (Hunter)
Right ascension: 05h, 55m, 10s
Declination: +07 deg, 24', 25"
Distance: ~700 ly

Betelgeuse is a huge red supergiant star nearing the end of its life. It's expected to die in a spectacular supernova explosion, with recent observations leading astronomers to predict it might happen within the next million years. Unfortunately, this will punch one of the pivotal dots out of one of the most beautiful constellations. Constraining the star's colossal size is tricky, but astronomers believe it might be large enough to swallow everything inside the orbit of Saturn if it replaced our Sun.



Rigel Kentaurus (Alpha Centauri)

Constellation: Centaurus (Centaur)
Right ascension: 14h, 39m, 36s
Declination: -60 deg, 50', 02"
Distance: 4.3 ly

Our nearest neighbouring star system, Alpha Centauri, hosts two very Sun-like stars, of which one is now known to harbour an Earth-sized planet. Could it be that a habitable Earth-like world has co-habited our little corner of the Milky Way? If so, we may be on the verge of discovering it, and this would become the most exciting exoplanet discovery to date. With today's technology it would take over 50,000 years to travel there. With one more revolution in physics, the 4.3 light year gulf to Alpha Centauri might be very manageable indeed. For now, we'll just have to admire the system from afar.

What's in the sky?

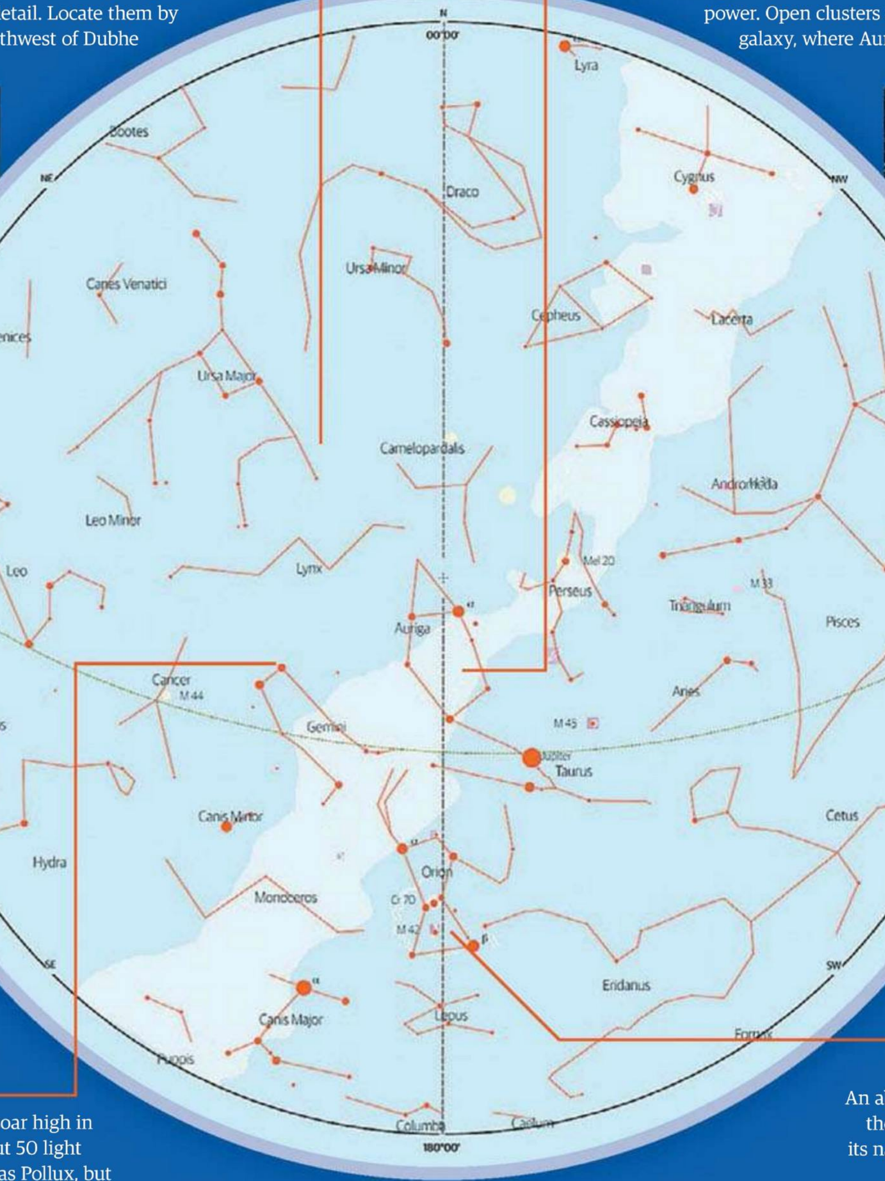
As 2012 comes to an end, many of us will celebrate another year of accomplishments. Why not celebrate the wonder of the sky, too?

Bode's Nebulae (M81 & M82)

Visible even in binoculars or a small telescope, this beautiful pair of galaxies is an awesome sight. M81 is a near face-on spiral, whereas M82 appears like a cosmic cigar. The two are physically interacting and are close enough together to be nicely framed with good detail. Locate them by sweeping about ten degrees northwest of Dubhe (Alpha Ursae Majoris).

Auriga Clusters (M36, M37 & M38)

Auriga hosts many star clusters, but the greatest must be the three catalogued by Charles Messier. Found in the southern half of the constellation, the magnificent trio are individually very interesting, but just unmissable when framed together at low power. Open clusters are common in the plane of the galaxy, where Auriga lies, and remind us that the Milky Way is a spiral.



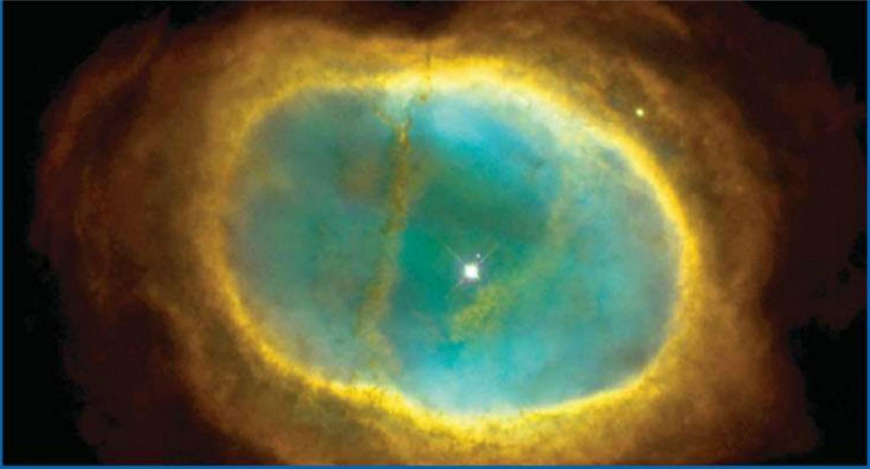
Castor

The heavenly twins of Gemini soar high in the sky this season. Castor, about 50 light years away, isn't quite as bright as Pollux, but is known as Alpha nevertheless. In a telescope, Castor is split as a beautiful close binary star, and each is known to be a spectroscopic binary. The two visible stars orbit each other about once every 470 years.

Northern hemisphere 00.00 UTC 15 December 2012

Orion Nebula (M42)

An absolute must-see for the season, the Great Orion Nebula lives up to its name. As a young stellar nursery, it glows from the brilliant heat produced by powerful infant stars at its core. In binoculars or a telescope, it shows a distinct 'bow' shape, and can be found in the middle of Orion's sword, south of his belt.

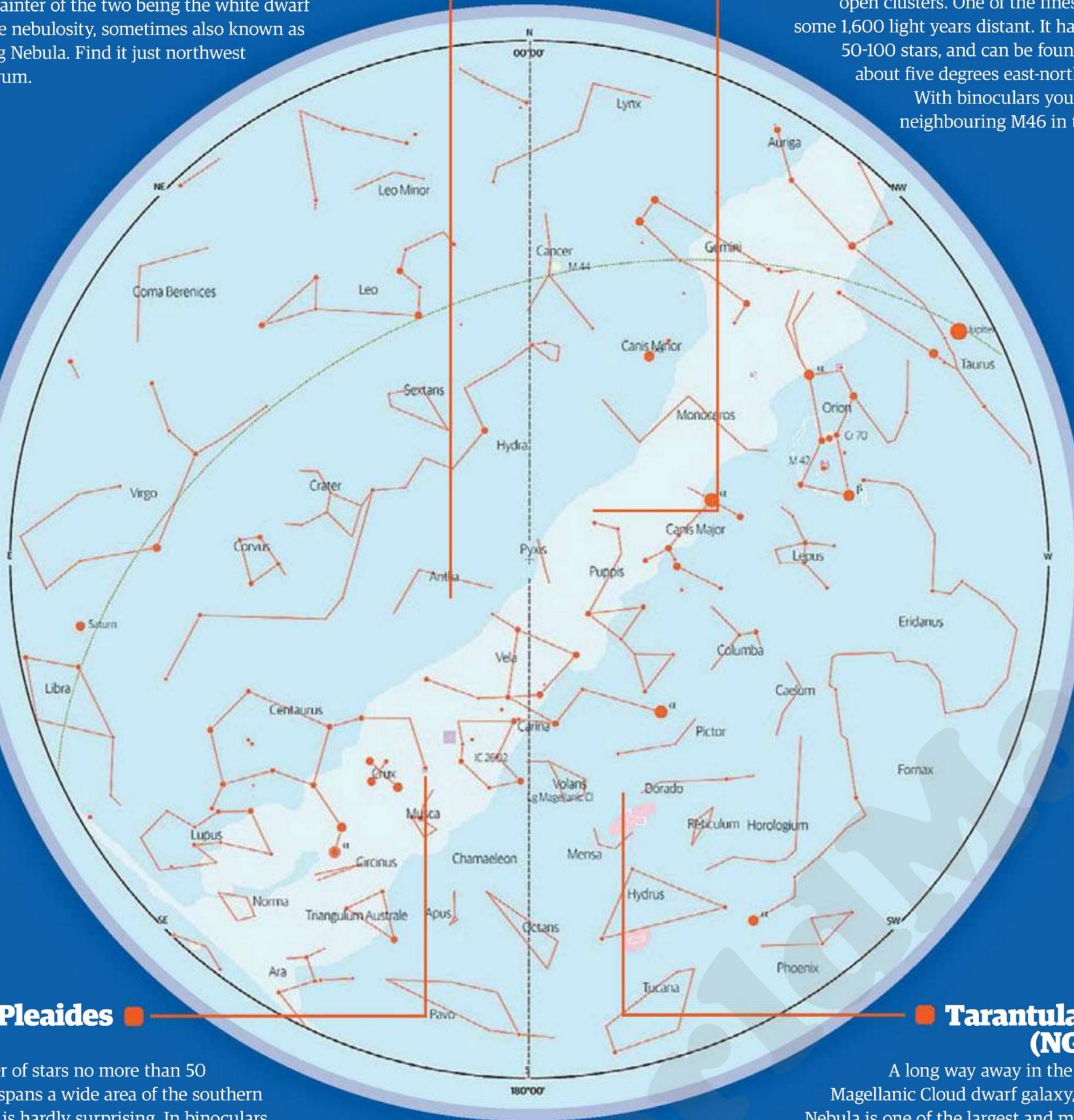


Eight-Burst Nebula (NGC 3132)

Sitting pretty in the constellation of Vela, the Sail, the Eight-Burst Nebula is a fine sight in a larger telescope at high power. The dim central star at the centre is really a double, with the fainter of the two being the white dwarf responsible for the nebulosity, sometimes also known as the Southern Ring Nebula. Find it just northwest of the star q Velorum.

M47 (NGC 2422)

The frequently overlooked constellation of Puppis (the Poop Deck) actually runs through the Milky Way, and naturally contains a large number of open clusters. One of the finest is M47, lying some 1,600 light years distant. It harbours around 50-100 stars, and can be found by sweeping about five degrees east-northeast of Sirius. With binoculars you may also spot neighbouring M46 in the same field.



Southern hemisphere
00.00 UTC
15 January 2013

Southern Pleaides (IC 2602)

This young cluster of stars no more than 50 million years old spans a wide area of the southern sky, and its name is hardly surprising. In binoculars or a widefield telescope, the cluster appears just as magnificent as the Taurean, 'northern' Pleiades. It too can also be seen with the unaided eye, and can be found simply by locating Theta Carinae, which the cluster surrounds.

Tarantula Nebula (NGC 2070)

A long way away in the orbiting Large Magellanic Cloud dwarf galaxy, the Tarantula Nebula is one of the largest and most active star-forming regions in the Local Group. If we put it in place of the Orion Nebula, it would cast shadows at night. This colossal cloud looks remarkable in telescopes, showing plenty of detail and structure. Find it first with the unaided eye!

Me & My Telescope

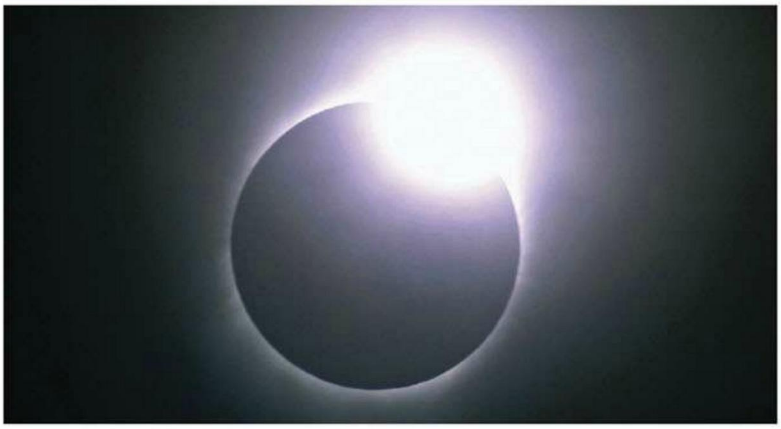
Send your astronomy photos or pictures of you with your telescope to **photos@spaceanswers.com** and we'll showcase them every issue

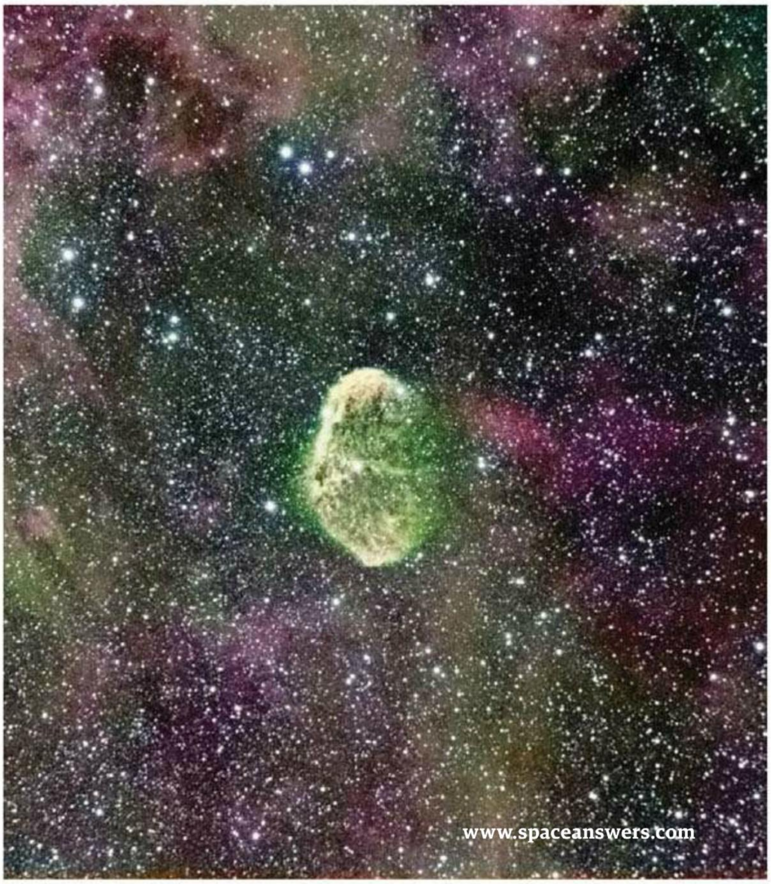
Nick Howes, UK

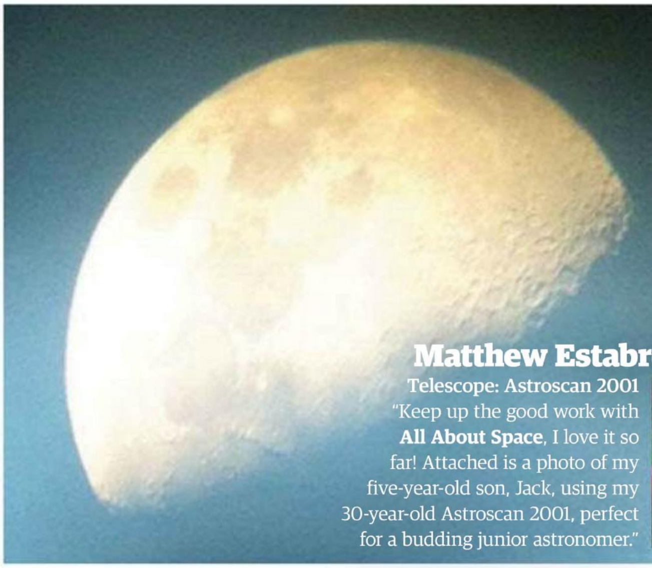
Telescope: TMB105 f6.2/Celestron C11/others

"From my father taking me to see *Star Wars* at the age of seven and my parents letting me stay up to watch the Viking/Voyager news in the Seventies to my grandmother buying me a telescope for Christmas aged nine, these are just some of the reasons I got into and love astronomy so much.

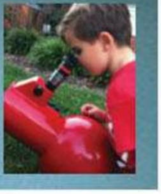
"As the programme manager for the Faulkes Telescope I observe and do science research on comets and asteroids, but from home as an amateur observer, as well as comets and asteroids I also love imaging nebulous regions in narrowband."







Matthew Estabrook, USA



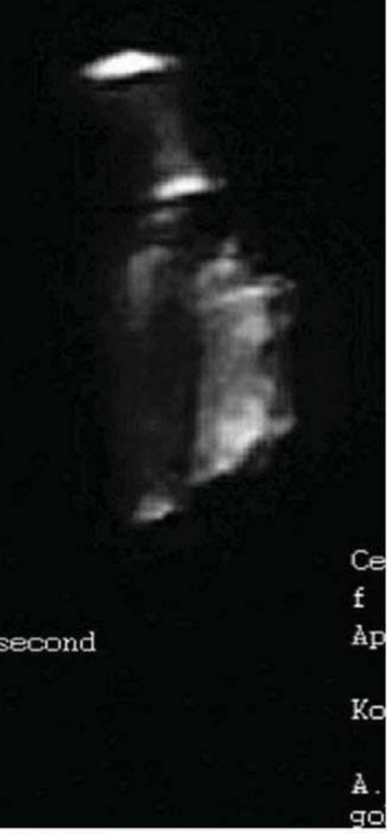
Telescope: Astroscan 2001
"Keep up the good work with **All About Space**, I love it so far! Attached is a photo of my five-year-old son, Jack, using my 30-year-old Astroscan 2001, perfect for a budding junior astronomer."

Ben, UK

Telescope: Celestron Nexstar
"I got this telescope as a Christmas present about a year ago. My favourite objects include the Moon and the Pleiades star cluster."

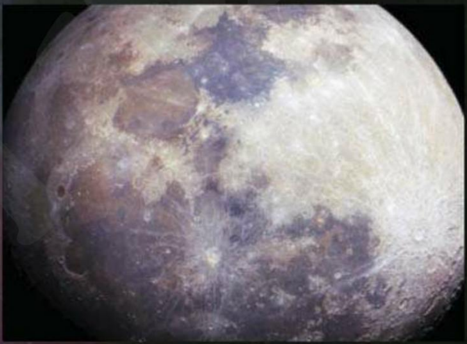
Gökhan Yetis, UK

Telescope: Celestron AstroMaster 70AZ
"I'm an amateur astronomer and astronomy student. I took this picture of the night sky using my Celestron AstroMaster 70AZ and my Kodak EasyShare M532 camera. A few days later I was looking at the images I'd taken and I noticed this strange object. It appeared really small, so I cropped and magnified the original image. I've sent it to many places to get some information but haven't been able to find out anything about it. I mostly take images of the Moon, Jupiter or Saturn but I'm a bit limited and can't take any images of deep sky objects. It was pure luck that I managed to get this picture."



Tanja Carruthers, Johannesburg, South Africa

Telescope: Celestron 11" CGEM DX
"My dad introduced the stars to me at a young age, but astrophotography is a recent hobby. I love the challenge of imaging things the eye can't see, my favourite imaging objects being nebulas and galaxies – or anything spectacular! The colours on the photo of the Moon represent iron and mineral deposits. Blues indicate titanium-rich areas, whereas yellows and purples are relatively deficient in these minerals."



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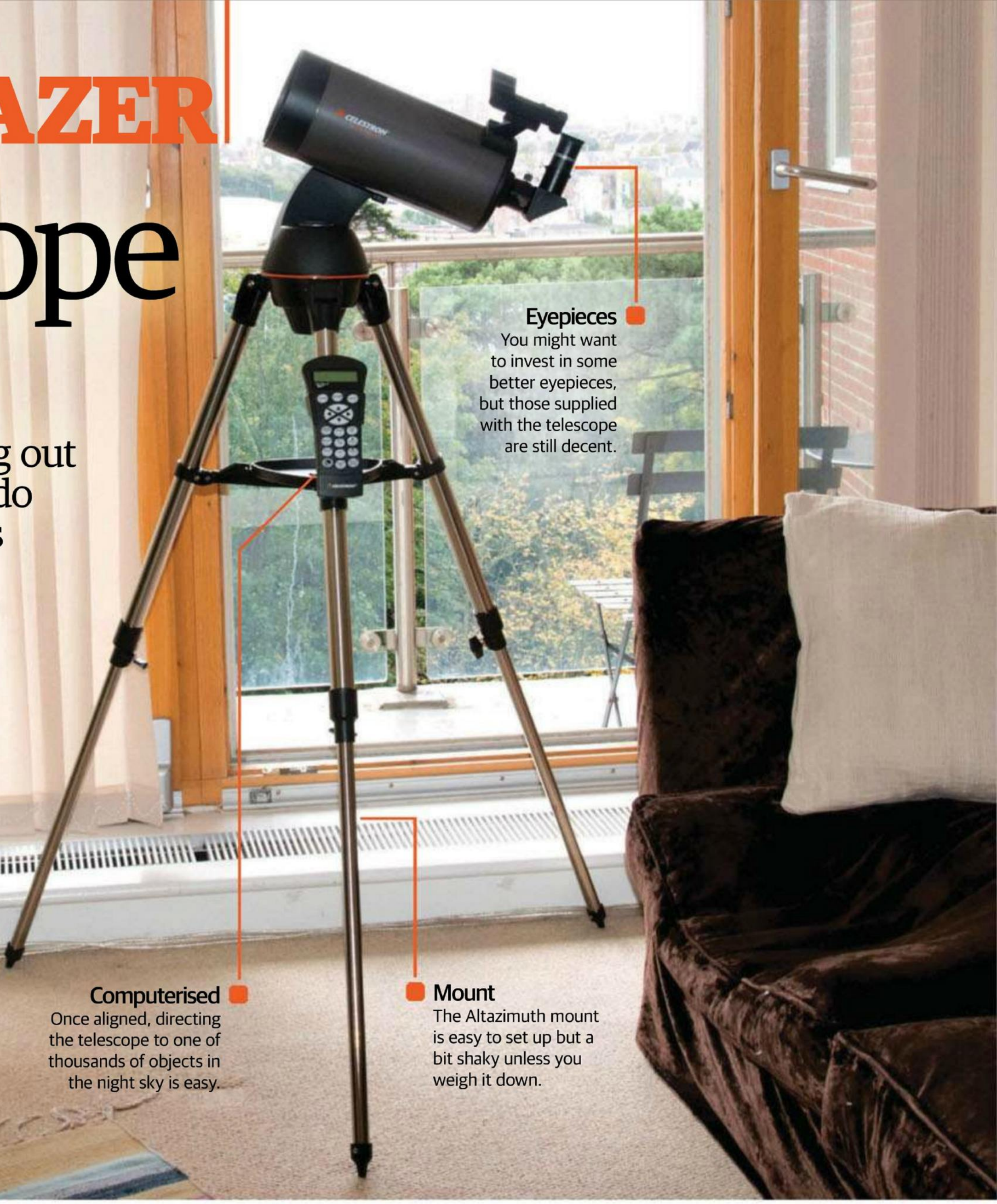
Telescope advice

Whether you're starting out or looking to upgrade, do this month's telescopes pass muster?



Eyepieces
You might want to invest in some better eyepieces, but those supplied with the telescope are still decent.

Computerised
Once aligned, directing the telescope to one of thousands of objects in the night sky is easy.

Mount
The Altazimuth mount is easy to set up but a bit shaky unless you weigh it down.

All About Space EDITOR'S CHOICE

The large aperture will provide you with great views of the cosmos

Celestron NexStar 127 SLT

Cost: £359 ($575)
From: www.sherwoods-photo.com
Type: Maksutov Cassegrain
Aperture: 127mm
Focal Length: 1,500mm
Mount: 300x

This computerised Celestron telescope boasts a hefty aperture and impressive optics to give you great views of the cosmos with minimal complications.

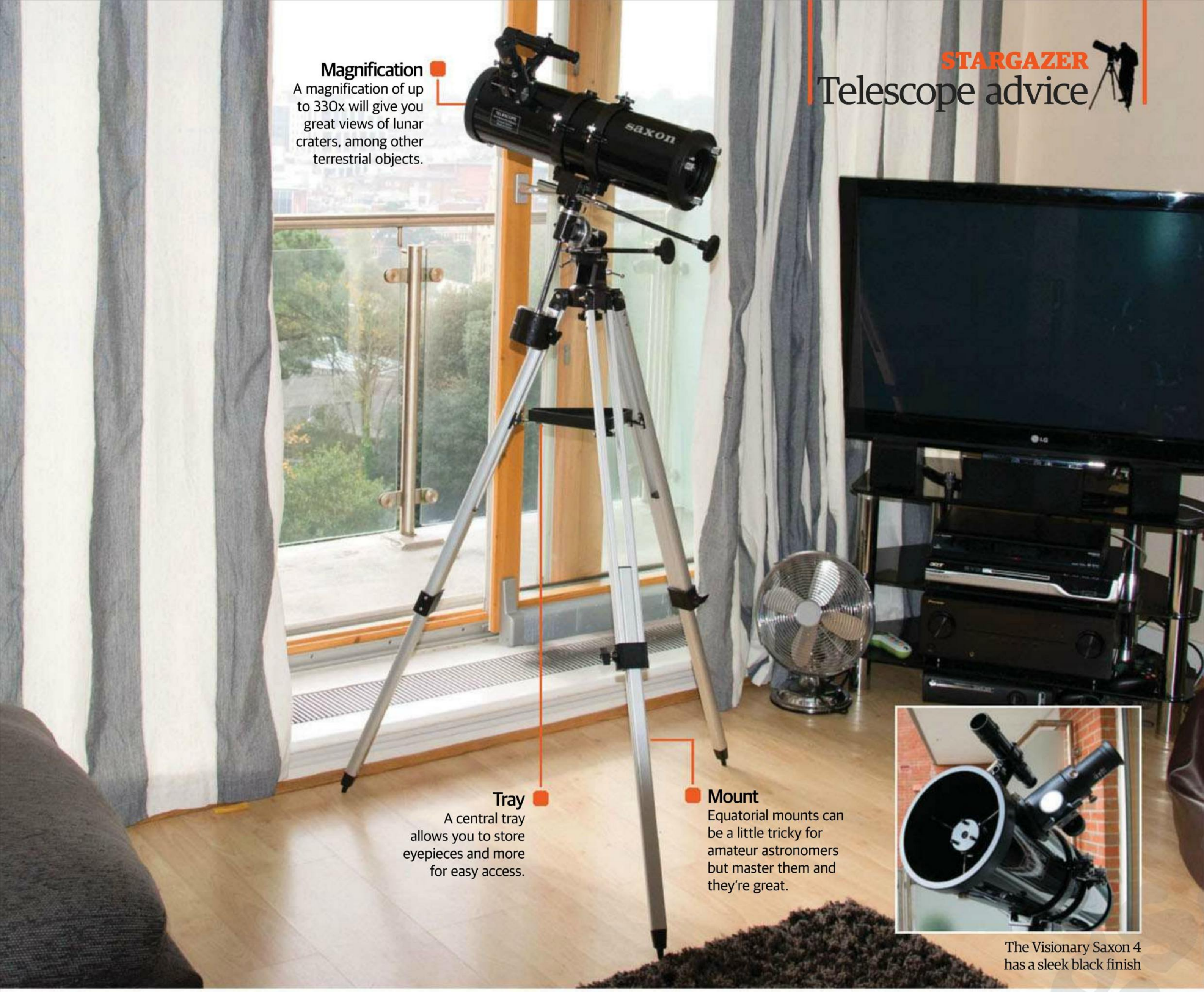
From the off, setup is a breeze. The mount is pre-assembled (apart from the tray and controller), so all you need to do is attach the telescope. Once you've done that, you're almost ready to get started, but first you'll need to learn how to align the telescope, which can be tricky to start with.

Getting down to observing, you'll be able to get some great views of the cosmos thanks to the mammoth database of over 4,000 celestial objects. Inputting an object is easy with the controller, and once aligned properly you'll have no problem finding what you're looking for.

With the included accessories, the views you'll get are good, if not great. You might want to invest in slightly better eyepieces, which will make a considerable difference. That being said, the quality of the telescope for the price is very good, and if this is your first telescope then you'll be pleasantly surprised at just how well you can see objects from the Moon to distant galaxies. The only other drawback was the mount, which can be a bit shaky.

Overall, we loved this telescope. Its portability only adds to its appeal, and it's great value for money. ●

The database includes thousands of objects



Magnification
A magnification of up to 330x will give you great views of lunar craters, among other terrestrial objects.

Tray
A central tray allows you to store eyepieces and more for easy access.

Mount
Equatorial mounts can be a little tricky for amateur astronomers but master them and they're great.

The Visionary Saxon 4 has a sleek black finish

The Visionary Saxon 4 offers some great views of distant objects

Visionary Saxon 4

Cost: £209 ($335)
From: www.opticalhardware.co.uk
Type: Reflector
Aperture: 114mm
Focal Length: 1,000mm
Mount: 330x

This telescope is well suited for a beginner in astronomy, with a low price range and decent optics.

Everything you need to view the cosmos is included here, so you won't need to purchase any additional accessories. Making minor adjustments to the mount to find what you're looking for is relatively easy, and you'll get some pretty decent views through the 114mm aperture.

In addition, with a magnification up to 330x, you'll be afforded some fantastic views of the Moon, its craters and other terrestrial objects in the Solar System. We found our observations to be much better than we expected, and we also got some great views of distant objects beyond the Solar System.

The mount isn't as sturdy as we would have liked and if you're not used to using an equatorial mount and you're just getting started in astronomy, you might struggle a little bit with the complexities. That being said, the Visionary Saxon 4 does a good job of keeping things simple, and the pre-assembled mount and telescope are both very portable, so you shouldn't have a problem taking this telescope out and about.

We had good fun with this telescope, and we'd say it's a good starting point for a beginner in astronomy who isn't fussed about computerised controls and wants to shop on a budget. ■

Astronomy kit reviews

Must-have products for budding and experienced astronomers alike

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All About Space EDITOR'S CHOICE
BRIAN MAY PATRICK MOORE CHRIS LINTOTT
THE COSMIC TOURIST
VISIT THE 100
PHILIP'S MOON MAP
MORE THAN 500 FEATURES NAMED AND INDEXED
CELESTRON

1 Binoculars: Celestron SkyMaster 25x100

Cost: £350 ($560)
From: www.hama.co.uk

These excellent binoculars from Celestron are a great way to get a brilliant view of the cosmos while you're out and about, or even just sitting in your garden. Be warned, though, as they are absolutely massive. While this makes them quite cumbersome (especially without a tripod), you'll get amazing views. With 25x magnification, the SkyMaster 25x100 provide exceptional quality visions of the night sky, allowing you to observe the Moon in great detail, among other celestial objects. The giant objective lenses offer maximum image brightness in low light so you'll be able to make out night sky objects, made all the more comfortable by the rubber coverings. A great choice for astronomers of all levels. ■

2 Scope: Celestron Travel Scope 70

Cost: £110 ($175)
From: www.hama.co.uk

Binoculars too small? Telescope too big? Then you might want to get yourself a travel scope, a mid-range way to view the night sky without lugging around a large piece of equipment. The Celestron Travel Scope 70 is small and portable, allowing you to experience the joy of using a fully fledged telescope but in a smaller package. An included backpack ensures you'll have no problems carting it around, and its so easy to set up that within minutes you'll get some fantastic views of celestial objects. The aluminium tripod is stable, while the optical elements provide clear and crisp views of the cosmos. This is a great all-in-one package at an affordable price that we'd highly recommend. ■

3 Guide: Philip's Moon Map

Cost: £6.99 ($11)
From: www.sherwoods-photo.com

A must for Moon gazers everywhere, the Philip's Moon Map contains over 500 named features of the near side of the lunar surface that you will be able to identify with binoculars or a telescope. There is a sizeable amount of accompanying text that highlights the best ways to see the Moon, from its motion around the Sun and its phases, to the best ways to take photos of some of its key features. Each landmark on the Moon is also labelled with its co-ordinates so you'll have absolutely no problems finding them with a telescope or a pair of binoculars. There are also close-up images of some lunar objects, as well as the far side of the Moon, so you'll know what you can expect to see. If you're fascinated by the Moon then you'll definitely want to pick this up. ■

4 Book: The Cosmic Tourist

Cost: £25 ($40)
From: www.carltonbooks.co.uk

This fantastic book takes you on a tour of the universe at "the speed of thought", beginning at planet Earth and heading right out to the edge of the observable universe. Co-authors Brian May, Patrick Moore and Chris Lintott have done an excellent job of writing clear and informative text, together with some fascinating images and impressions of sights along the way, ensuring that you'll be able to get to grips with even the most complex of topics. Along the way you'll be treated to fantastic views of the Sun, a guide to the exploration of Mars, amazing information about supergiant stars and nebulas, and much more. For a full guide to the universe this is a book like no other, and the balance of informative text and gorgeous imagery makes it well worth picking up. ■

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A. Earth B. Mars C. Jupiter

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Nexstar SLT 127

The NexStar SLT 127 Maksutov Cassegrain is an affordable mid level computerised GoTo telescope, it is loaded with valuable design features. Pre assembled, adjustable stainless steel tripod and quick release fork arms and tubes, means that the NexStar 127 SLT telescope can be set up in a matter of minutes – with no tools required! Enabling you to see details of the lunar surface, Venus and its phases, polar caps on Mars, Jupiter and its four moons, Saturn with its rings plainly visible and much more! The NexStar SLT127 can also be used as a land-based spotting telescope.

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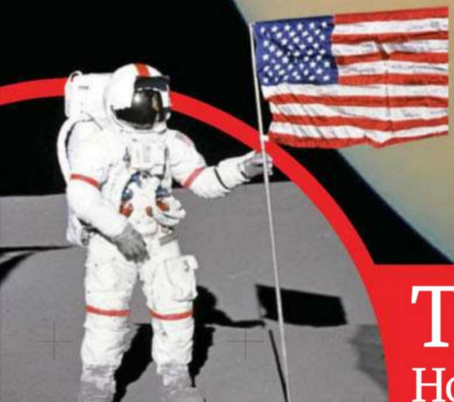

The first American space hero

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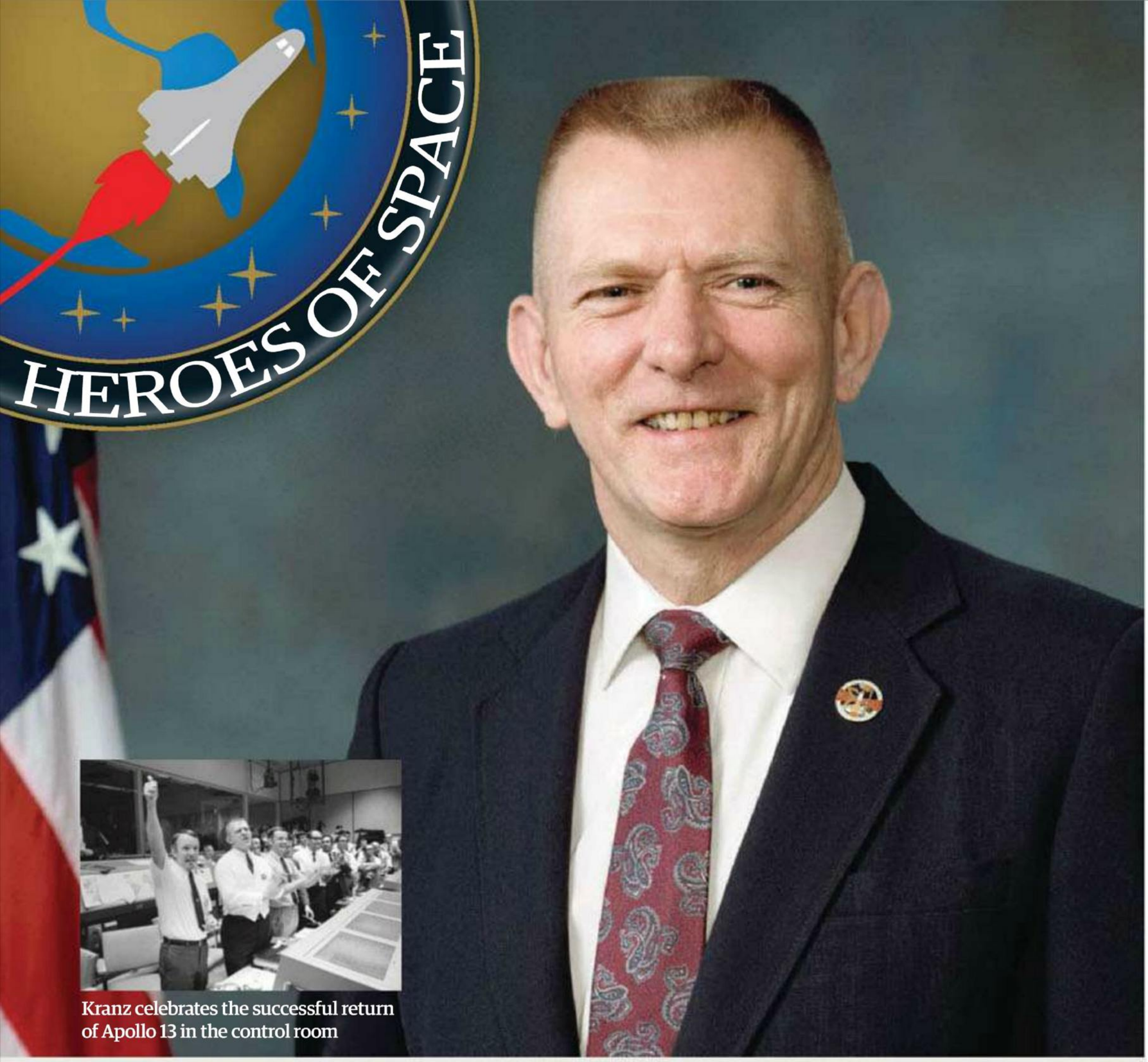

Kranz celebrates the successful return of Apollo 13 in the control room

Gene Kranz

One of NASA's most decorated flight directors for whom failure was not an option

Eugene Francis 'Gene' Kranz, born in Toledo, Ohio, USA on 17 August 1933, developed an early interest in aeronautics that would lead to a long and distinguished career with NASA.

After growing up on a farm, Kranz went to Parks College in St Louis, Missouri to study aeronautical engineering, graduating in 1954. He then spent four years in the Air Force before joining NASA in 1960. His first taste of space came on the first and third Mercury missions, in 1961 and 1962, during which he integrated Mercury Control with the Launch Control Team. For the fourth Mercury mission he was promoted to assistant flight director, and by the fourth Gemini mission he was flight director.

When the Apollo missions were announced, Kranz was assigned to all the odd-numbered missions. This included Apollo 11, with Kranz present in the control room when Armstrong and Aldrin stepped on to the lunar surface. He is most famous, however, for his role in the ill-fated Apollo 13 mission. When an oxygen tank ruptured and left the spacecraft stranded in space, it was Kranz's quick-thinking that enabled the astronauts to safely return home.

Kranz was part of the 'White Team' (the others being 'Red' and 'Blue') for Apollo 13 and, as part of the rotation schedule, his team was manning the control room when the problem occurred. Kranz and his team gave the astronauts specific instructions to ensure their survival, which included setting constraints for critical consumables such as oxygen, electricity and water.

Kranz also had to choose between firing the spacecraft's rockets and returning it home immediately as it drifted away from Earth, or using the Moon to slingshot the Apollo 13 crew back safe and sound. He picked the latter option, despite the longer route, which would prove crucial in the success of bringing the spacecraft home. It was on this mission that Kranz rose to stardom, not only for his exceptional discipline under pressure, but also for his famous white vests that would become iconic of his remarkable career.

Interestingly, Kranz never actually used the phrase "Failure is not an option" during the mission, as was popularised in the 1995 movie *Apollo 13*. However, he took such a liking to the phrase and its connotations that he used it for the title of his autobiography in 2000.

Kranz later served as flight director through Apollo 17 and also oversaw some of the Skylab missions. He became deputy director of NASA mission operations in 1974 and director in 1983, overseeing the launch of the Space Shuttle, before retiring in 1994 after flight STS-61 successfully repaired the Hubble Space Telescope.

In 2010, he was voted the second most popular space hero after Neil Armstrong in a Space Foundation survey, a true testament to his popularity and lasting legacy. ■

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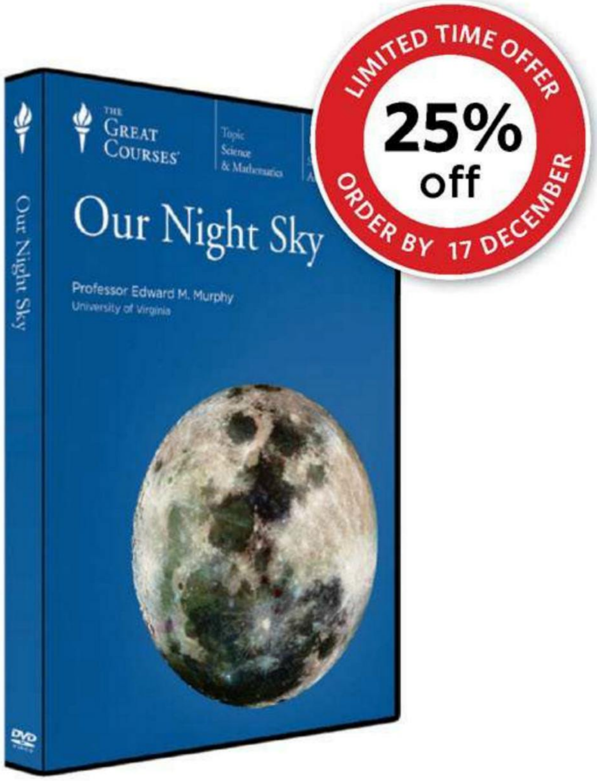

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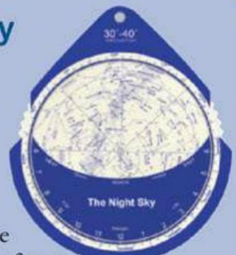

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